NINE LAKES ON SALT SPRING ISLAND, B.C.: SIZE, WATERSHED, INFLOW, PRECIPITATION, RUNOFF AND EVAPORATION

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A Background Report for the Cusheon Watershed Management Plan and Steering Committee.
Based on data from surveys by various ministries of the governments of British Columbia, Canada, and other agencies.

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SUMMARY

(1) St. Mary Lake dwarfs all the other lakes of Salt Spring, in size and amount of standing water. St Mary contains about 16 million cubic metres of water, while the other lakes range from a little over 2 million down to only about 0.1 million cubic metres.

(2) In contrast to lake size, the greatest yearly inflows of water occur in Cusheon and Ford Lakes, each with almost 4 million cubic metres per year (m^3/yr). This is the *water supply*. St. Mary and Blackburn have somewhat smaller yearly inflows of about 3 million m^3/yr, followed by Stowell Lake with almost 2 million m^3/yr. Inflows to Bullocks, Maxwell, Weston and Roberts Lakes range from 1 million down to less than 0.6 million m^3/yr. Diversions into Maxwell Lake have boosted its yearly inflow from last place to sixth place among the nine lakes.

(3) The flushing speed in each lake can be expressed as the theoretical times for 95% replacement of water molecules. The fastest are Blackburn and Ford Lakes, which would average just over a month to replace 95% of their old water molecules. Stowell Lake has an average replacement time of about four months. Time for Cusheon Lake is almost one year, and Roberts and Bullocks Lakes are similar to that. Maxwell Lake, after diversion of streams into it, has a 95% replacement time of almost eight years. St. Mary Lake is the slowest to flush, with 95% replacement of almost fifteen years. (These theoretical times assume a steady inflow which is not true, but the values provide some sense of realistic flushing times.)

(4) Yearly rain and snowfall has historically averaged 0.98 metres in the Cusheon drainage basin. The average for all of Salt Spring Island is 0.959 metres in a year.

(5) The annual surface runoff, directly from the land into creeks, is estimated as 48% of the amount of rain and snow that falls. This is the robust average of eleven estimates by earlier workers at various locations on Salt Spring Island. Accordingly, the runoff of 48% was used for calculations in this report.

(6) All of the above estimates are based on available data from past years, and the exact values given in the body of this report are considered to be the best available at present. All estimates are given as yearly averages, so they do not attempt to deal with seasonal extremes in rainfall and creek flow. There would also be major year-to-year differences from the averages given here. Future climate changes could change the values.

(7) Salt Spring lakes are unusual in two respects, compared to “typical” lakes elsewhere in Canada and the world. First, the major inflow of water comes as heavy winter runoff, followed by dry creeks in summer. Second, most of the lakes are of unusual size compared to their drainage basins. Blackburn, Ford and Stowell are small lakes set in relatively large basins. Weston, Maxwell and St. Mary are large lakes in small basins. Roberts, Cusheon, and Bullocks Lakes are more typical in size, relative to their drainage areas.

This report has been revised from its 2007 version, in order to incorporate definitive surveys of two watershed areas (Grange 2008a, b).

INTRODUCTION

- One purpose of this report is to collect scattered background data on lakes and water movements on Salt Spring Island, and make those values easily available to later workers. The data-sets originated in lake surveys by ministries of the British Columbia government and programs of other B.C. and Canadian agencies.
- A second purpose is to estimate some standard values for lake and watershed sizes, rainfall, runoff and evaporation. There is special focus on the three lakes in the Cusheon watershed, since this is a background report for the Cusheon Watershed Management Plan (CWMPSC 2007).
- A third purpose is to compare sizes and flows of the nine largest lakes on the island.
- A final purpose is to show the methods and rationales that were used here, in processing the existing sets of data to arrive at standardized values.

RESULTS

The general findings are shown in Figures 1 and 2, and tabulated in Table 1. A commentary section follows, then an explanation of how the numbers were calculated, and finally a detailed appendix.

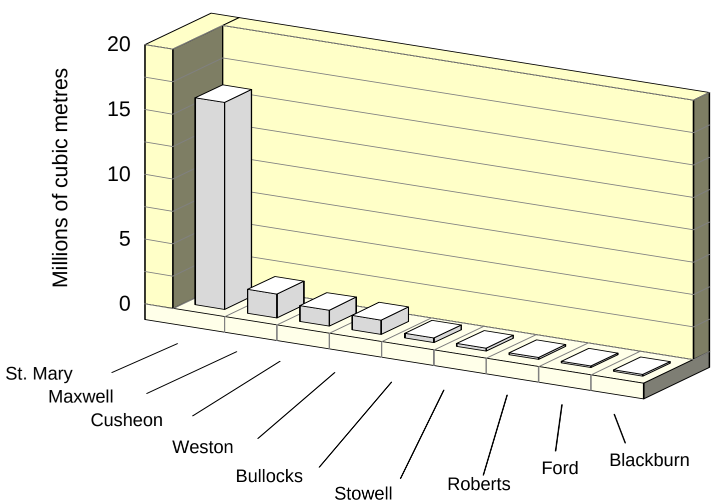

Figure 1. Standing water volumes in nine lakes on Salt Spring Island.

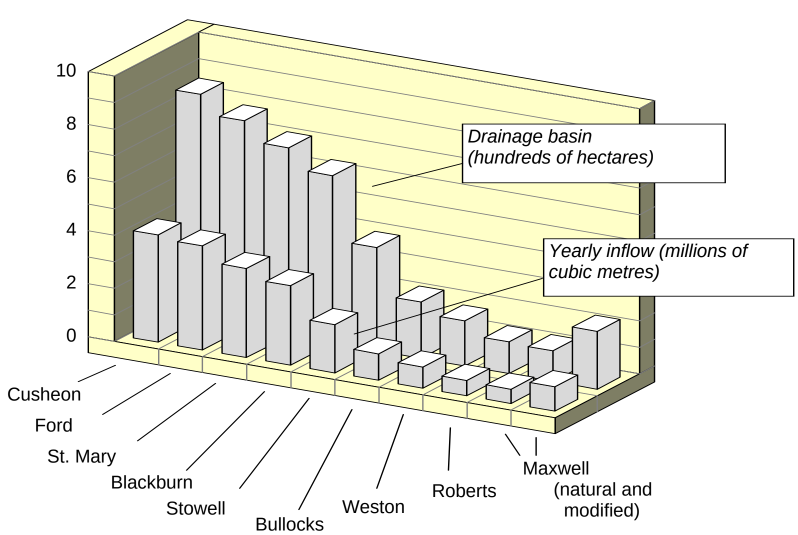

Figure 2. Areas of drainage basins and yearly inflows of water to nine Salt Spring lakes.

Table 1. **Physical characteristics of the larger lakes on Salt Spring Island**. Lakes are in order of drainage basin size. Information is from surveys and reports in the footnote***.

1. Lake	2. Depth (metres)		3. Surface area (hectares)	4. Volume (thousands of m^3)	5. Drainage basin, lakes included (hectares)	6. Yearly inflow* (thousands of m^3)	7. Time to fill if empty (years)	8. Time for 95% replacement of water	
	Mean.	Max.						Years	Months
Cusheon	4.5	9.1	26.9	1,214	839**	4,100	0.30	0.89	11
Ford	3.0	3.5	4.25	127	780	3,915	0.032	0.097	1.2
St. Mary	8.8	16.7	182	15,960	690	3,269	4.9	14.6	176
Blackburn	3.0	5.0	3.08	92.4	619**	2,943	0.031	0.094	1.1
Stowell	4.6	7.5	4.57	210	389	1,806	0.12	0.35	4.2
Bullocks	3.9	7.0	9.40	370	212	1,005	0.37	1.1	13
Weston	5.9	12.2	18.5	1,090	170	789	1.4	4.1	50
Roberts	4.1	8.2	3.44	140	120**	586	0.24	0.72	8.6
Maxwell Original Modified	6.5 7.7	17.0 19.2	27.7 29.9	1,810 2,310	115 217	533 910	3.4 2.5	10 7.6	122 91

* Inflow is estimated from size of the drainage basin, using annual precipitation in that region, and an average (island) value for proportion that runs off the land. Inflows for the three lakes of the Cusheon system are estimated from a more detailed model shown in Table 5 of the Appendix.

** Areas of the three drainage basins in the Cusheon system were estimated by Islands Trust (Korteling 2006); areas shown here include basins of upstream lake(s). Definitive areas of the total Cusheon and St. Mary basins were measured by Grange (2008a, b) and are incorporated into this table.

*** Maps and data from government lake surveys are provided on a web site of B.C. Environment, at time of writing http://a100.gov.bc.ca/pub/fidg/bathyMapSelect.do. (Cusheon 1972, Ford 1978, St. Mary 1978, Blackburn 1972, Stowell 1960, Bullocks 1981, Weston 1960, Roberts 1972, Maxwell 1981). Precipitation for areas of Salt Spring Island were provided by Aston (2006), Barnett et al. (1993), Hamilton (1995), Environment Canada (2006) and Watson (2006b). Other information on lakes and flows was given by Barnett et al. (1993), Hamilton (1998), Holms (1996), McKean (1981), Nordin (1986), Nordin et al. (1983), Sprague (2007b), and Watson (2006a,b).

COMMENTS ON THE RESULTS

From Figure 1 and the left side of Table 1, it is obvious that St. Mary Lake has the greatest depth, and by far the greatest surface area and volume of standing water. However, for size of drainage basins, four lakes have similar-sized basins -- Cusheon, Ford, St. Mary and Blackburn (Figure 2 and column 5 of Table 1). Maxwell Lake is the second biggest in standing volume, but in its natural state it has the smallest drainage basin.

The size of drainage basin (Table 1, column 5) determines the total amount of rain and snowfall that runs off the land into the lake. Accordingly, the yearly inflows in column 6 of the table reflect the sizes of basins, with some slight variation because of differences in local rainfall.

The yearly rain and snowfall used for the Cusheon watershed was 0.98 metres per year. That is a 29-year average at a location close to the centre of the basin which drains to Cusheon Lake, as measured meticulously by Robert Aston (Aston 2006). Precipitation varies around the island, so records from other locations were used for particular lakes. A Salt Spring average of 0.959 metres was used for some watersheds without any weather records. (See Appendix for details.)

About half of the annual rain and snowfall runs off the land into creeks and eventually into the lakes (48% of precipitation). The amount of inflow to each lake was obtained by multiplying the annual precipitation by 48%, then multiplying by the area of the watershed (Figure 2 and column 6 of Table 1). The average value of 48% was derived from eleven estimates by earlier workers in different parts of the island.

Clearly, the annual inflow is greatest for the lakes with the biggest drainage basins, as shown by Figure 2 and Table 1. Cusheon, Ford, St. Mary and Blackburn Lakes have inflows of three to four million cubic metres per year. The flow into any one of those four lakes would supply the yearly needs of 11,000 to 15,000 households. Of course the problem is little storage of water. Much of the heavy flow during the cool seasons moves right through the smaller lakes and down to the sea. Next in size of yearly inflow is Stowell Lake with an input of almost two million cubic metres. Bullocks, Weston, Roberts and Maxwell Lakes have annual inflows of only a million cubic metres or well below that.

The values for flushing shown in columns 7 and 8 of Table 1 are determined by the data in the previous columns. A small lake with a large drainage basin flushes quickly (e.g. Ford and Blackburn Lakes). Conversely, a large lake with a relatively small or average-sized basin flushes slowly (e.g. St. Mary Lake).

The numbers in column 7 ("Time to fill if empty") are clearly unrealistic because lakes do not start from empty. These numbers are simply the volume of a lake divided by its yearly inflow, often called "*flushing times*". Such values are useful and widely used by engineers and other specialists for designing water systems, because they can be calculated as an exact number. However, they do not convey a realistic impression of the time that is necessary to flush out old water.

The times for 95% replacement of water molecules (column 8) are more realistic although they are only theoretical estimates for purposes of comparison. The values are obtained by multiplying the "time to fill" by a factor of 3.0, derived from a mathematical relationship (Sprague 1969).

Estimates are theoretical since they assume a constant inflow and random mixing, whereas the real pattern of Salt Spring lakes is heavy flow in winter and little or none in summer. Also, most Salt Spring lakes would mix completely in the autumn, then partially or wholly mix throughout the winter and spring. In summer, only the warm upper layer is likely to mix, in a lake with appreciable depth. Despite these qualifications, 95% replacement time is useful as a realistic estimate of time to replace most of the old water in a lake.

Table 1 and Figure 2 show that Blackburn and Ford Lakes, with their moderate size and relatively large basins, have the fastest 95% replacement times of about a month. St. Mary Lake is the slowest to replace its water, with a time of almost 15 years. Maxwell Lake is also slow, with a natural 95% time of 10 years. The current time for Maxwell is 7.6 years, because two creeks have been partially diverted to supply it, and the lake level has been raised by a small dam.

Limitations. This report gives some general or "ball-park" comparisons. It attempts to compare "average" years, with estimates derived from recent historical data. Of course, any particular year will differ from the average. Furthermore, there are extreme seasonal changes which do not show up in yearly averages (see paragraphs immediately below). This report does not attempt to predict the effects of climate change; Watson (2006b) examines that topic.

Unusual nature of Salt Spring lakes. Two features of lakes on the Gulf Islands are unusual by national and international standards. These are (a) the atypical and violent seasonal changes in water flow and (b) the relative size of drainage basins for certain lakes.

(a) Any local person knows that the big water runoff comes during the wet seasons, usually November to April. In the other half of the year, creeks supply little or no water to the lakes. Elsewhere in Canada, the big flows usually come with the snowmelt and spring runoff. In many areas, summer rainfall keeps the streams running and the lakes overflowing.

And so in Salt Spring lakes, there tends to be a very rapid exchange of water during the wet seasons, and perhaps zero exchange during a long summer period. The average replacement times shown in Table 1 are clearly theoretical, since they smooth over these differences. The averages serve their purpose, however, in allowing a general comparison of local lakes.

(b) The local lakes vary enormously in size of drainage basins compared to the area of the lake. Freshwater scientists describe this as the ratio of the basin *(catchment area, CA)* to the surface area *(lake area, LA)*. Elsewhere in the world, this ratio of CA to LA varies from 976 down to 0.2, but the overall average is 54 (Kalff 2001). A more representative average ratio is 35, in the opinion of Dr. R.N. Nordin of the University of Victoria (personal communication). He obtained the average of 35 by deleting two unusual lakes with giant drainage areas.

The nine lakes of Salt Spring have a wide range of ratios for CA / LA, as listed immediately below. The ratio provides another way of judging a lake, and to some extent parallels the replacement times shown in Table 1. A large number (ratio) indicates a lake with a larger water supply than one might think from just looking at the lake. A small number means that the lake has a smaller water supply than one might judge from just looking at the size of the lake.

Blackburn	204	Roberts	33.9	Weston	8.2	
Ford	182	Cusheon	30.6	Maxwell modified		6.6
Stowell	84.1	Bullocks	21.6	natural		3.1
				St. Mary	2.9	

The lakes in the left-hand column (Blackburn, Ford and Stowell) have a large water inflow compared to their surface area. These, of course, are lakes with a fast replacement time (Table 1). The three lakes in the middle (Roberts, Cusheon and Stowell) are close to the international average of 35 in their catchment-to-surface ratio and could be called normal in this respect. The three lakes on the right (Weston, Maxwell and St. Mary)have small basins in relation to surface area, particularly St. Mary and Maxwell in its natural state. These are the drinking-water lakes for the North Salt Spring and Fulford Water Districts. Their large sizes are deceptive since they are not accompanied by large flows of water.

BRIEF EXPLANATION OF METHODS OF CALCULATION

The physical lake survey by the B.C. government provided the start for each lake. Surveys are on a Ministry of Environment web site (http://a100.gov.bc.ca/pub/fidq/bathyMapSelect.do at the time of writing). The surveys provide depths, areas and volumes of lakes. The accuracy is not known. The government bathymetric maps show very detailed depth contours, suggesting thorough work, but some surveys were done 49 years ago. A few lakes were surveyed twice and the differences were usually slight, with a couple of apparent anomalies. There was little choice but to accept the data, and the most recent or apparently reliable surveys were used.

Similarly, the areas of drainage basin could involve some inaccuracies. Areas were estimated in various reports of B.C. government agencies (see Appendix), and other workers adopted the values. The exception was the determination of areas in the Cusheon basin. These were done for each of the three lake basins by Brett Korteling (GIS coordinator for Islands Trust) for the Cusheon Watershed Steering Committee (Korteling 2006). He mapped the areas from recent computer-drawn contour maps. The result, 850.7 hectares down to the outlet of Cusheon Lake, was 17.5% bigger than the area of 724 hectares which had been accepted traditionally.

In 2008, a definitive survey of the three-lake Cusheon system was done by Grange (2008b) who ground-truthed the boundaries using global positioning devices. Total area was similar to that determined by Korteling (1.4% less) and this definitive value was adopted here (see Appendix).

Grange (2008b) carried out a similar definitive ground-truthing of the St. Mary watershed and derived an area that is used here and is 1% less than the previously-accepted area.

Average rain and snowfall on Salt Spring Island varies in different locations, from somewhat less to slightly more than one metre per year. For each lake, an average precipitation value was assigned from the closest weather station with a reliable set of data which extended over many years since 1975. The information was gathered from Environment Canada and various reports as listed in a footnote to Table 1. An average yearly value of precipitation for Salt Spring (0.959 metres) was obtained from the available records and used for Stowell and Weston Lakes which did not have nearby weather records. For the Cusheon watershed, the long-term average of Aston (2006) was used because of its reliability and its collection-point near the centre of the area draining to Cusheon Lake. Many Environment Canada stations ceased operations in the late 1990s, and had sometimes produced incomplete or irregular data before that.

Runoff from the land to the lakes is a proportion of the annual precipitation. Eleven estimates were derived from existing reports (Barnett et al. 1993; Hamilton 1995, 1998; Holms 1996; Korteling 2006; McKean 1981; Nordin et al. 1982, 1983; Watson 2006b; and by modelling of the Cusheon system). The eleven proportions were 0.385, 0.408, 0.42, 0.4459, 0.43545, 0.45548, 0.478, 0.4837, 0.5818, 0.5944, and 0.6463. They average 0.484 or about 0.48. The eleven values varied but the average appears robust; it remains the same if the lowest and highest values are omitted, and if the two lowest and highest values are deleted, the average changes only slightly to 0.47.

Runoff from the land was estimated for the drainage basins of all nine lakes by applying the average. The calculation is *[precipitation]* x *[basin area]* x *[runoff proportion]*. This is a simplification because it assumes the same runoff for all soil and vegetation types in the various basins. However, the resulting estimates appear to be reasonable. For example, the inflow estimate for Maxwell Lake is 533,000 cubic metres per year, close to an earlier estimate of 561,000 by Nordin et al. (1982). The average of 0.48 also agrees with an average of 0.497 estimated by Truscott (1981) for six Salt Spring lakes, by modelling.

For lakes in the Cusheon system, there was additional detail. Precipitation falling directly onto a lake was calculated separately, since 100% of it enters the lake (i.e. not a runoff proportion). Evaporation of 0.713 metres per year from lake surfaces (Watson 2006b) was assessed separately since it reduces outflows from upper to lower lakes. These refinements were not made for other lakes, but the error is less than 1% because evaporation and runoff balance each other, approximately. For Maxwell Lake, only 80% of the runoff from the "added" basins of Rippon and Larmour Creeks was included because their first autumn flushes have elevated phosphorus content and are not collected (Watson 2006a).

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APPENDIX. DETAILS OF SELECTING DATA AND CALCULATING VALUES

Sizes of lakes

The B.C. government has surveyed all nine lakes at various times. The maps of the lakes with depth contours, accompanied by values for size and volumes, are currently available at the government web site listed in the footnote of Table 1. The surveys were done at various times and by various branches or ministries as indicated below. If there were two surveys, the later one was chosen for this report. The earlier surveys were expressed in feet, acres, and acre-feet, and were converted to the metric units reported here.

Cusheon Lake. Surveyed in 1972 by the Fish and Wildlife Branch of the Department of Recreation and Conservation, with surface area of 26.9 hectares. The data from this original government survey are used here for depths, surface area and volume. A map with similar contours is given by Spafard et al. (2002); their tabulated measurements differ somewhat from the 1972 map. Although at first glance this appeared to be a new survey, it was only an approximate conversion of values from the old survey (personal communication, Dr. R.N. Nordin, University of Victoria) and had some evident anomalies. The old survey was used here..

There have been other reports giving the sizes of Cusheon Lake. Hamilton (1995) measured the surface area of Cusheon Lake as 27.9 hectares, a small difference from the ministry survey. Reports by other authors did not involve new surveys but were apparent restatements of the earlier measurements. One report was by Goddard (1976) who apparently misread the small unclear digits on the original map. Other reports by Barnett et al. (1993), Watson (1995), and Holms (1996) gave the earlier data with slight variations. The atlas of Spafard et al. (2002), mentioned above, was once available on the web but can no longer be found there.

Ford Lake. Surveyed in 1972 by the Fish and Wildlife Branch of the Department of Recreation and Conservation. A new survey was carried out by McKean (1981) of the Aquatic Studies Branch of the Ministry of Environment. He reported on four Salt Spring lakes. Depths were adopted from this later survey. However, the lake surface areas reported by McKean are clearly in error, by comparison with earlier measurements and by making measurements on the maps provided by McKean. Accordingly, the surface area for Ford Lake was taken from the 1972 survey. The volume of the lake was obtained by multiplying that earlier surface area by McKean=s average depth.

The values of McKean (1981) for Ford Lake were used in later reports by Barnett et al. (1993) and Watson (1995).

St. Mary Lake. Surveyed in 1978 by the Recreational Fisheries Branch, Habitat Management Section, of the Ministry of Environment. The same data for depth and surface area of the lake were adopted by Nordin et al. (1983), and Holms (1996). The present report adopts the depths, surface area, and volume of the 1978 survey.

The same values for size of St. Mary Lake have been listed by Barnett et al. (1993) and Watson (1995). Hamilton (1998) made a new estimate of the surface area of the lake using a planimeter on 1969 maps of B.C. Lands, Forests and Water, and obtained an area that was negligibly different (0.6% larger) from that of the 1978 survey which is used here. Holms (1996) reported on water quality of St. Mary Lake but did not deal with its size.

Blackburn Lake. Surveyed in 1972 by the Fish and Wildlife Branch of the Department of Recreation and Conservation. Later, surveyed by McKean (1881). The same rationale for selecting measurements was used here for Blackburn Lake, as was outlined above for Ford Lake. In other words, the mean depth of McKean was used, along with the surface area of the 1972 survey, and the product of those was adopted as the volume.

The values of McKean were used by Barnett et al. (1993) and Watson (1995).

Stowell Lake. Surveyed in 1960 by the Fish and Wildlife Branch of the Department of Recreation and Conservation. Also surveyed by McKean (1881). The same rationale for selecting measurements was used here, as was outlined above for Ford Lake -- the mean depth of McKean and the surface area of the 1960 survey were adopted, and their product is reported here as the volume.

The values of McKean were used by Barnett et al. (1993) and Watson (1995).

Bullocks Lake. Surveyed in 1981 by the Resource Analysis Branch of the Ministry of the Environment. McKean (1981) reported measurements for Bullocks Lake, but apparently these did not arise from a new survey. Accordingly, the 1981 values from the Ministry of the Environment were used here for depths, surface area and volume.

The values of McKean were used by Barnett et al. (1993) and Watson (1995).

Weston Lake. Surveyed in 1960 by the Fish and Wildlife Branch of the Department of Recreation and Conservation. These depths, surface area, and volume were adopted here.

The same values were used by Barnett et al. (1993), Watson (1995) and Nordin (1986). The latter report printed a lake volume which has been acknowledged as a miscalculation (personal communication, Dr. R.N. Nordin, Univ. of Victoria).

Roberts Lake. Surveyed in 1972 by the Fish and Wildlife Branch of the Department of Recreation and Conservation. The reported depths, surface area, and volume were adopted here. Later reports on Salt Spring lakes do not include Roberts Lake.

Maxwell Lake. Surveyed in 1981 by the Resource Analysis Branch of the Ministry of the Environment with a reported surface area of 27.7 hectares. There had been an earlier survey (1972) by the Fish and Wildlife Branch but it is not used here. It appeared to have a very erroneous value for the average depth. The depths, surface area and volume of the 1981 survey were adopted to represent the lake before its level was raised (called here, its "natural state"). Nordin et al. (1982) used the 1981 government survey data for lake size before modification.

Hamilton (1995) stated that the surface area of the lake was 26.3 hectares, but that value is anomalous because Hamilton=s Figure 4 clearly indicates an area of about 27.7 hectares when the lake is full to its old standard level of 2.82 metres on the Ministry of Environment gauge.

Since then, a small dam has raised the water level of Maxwell Lake to provide more storage of water for the North Salt Spring Waterworks District (NSSWD). The new "modified" depths have been taken from Barnett et al. (1993) and Watson (1995), who provide the same values. Two creeks have been diverted from their natural courses to supply the lake (Rippon and Larmour Creeks, see below). R.H. Watson (2006a) provided data on basin areas which included recent surveys by the NSSWD for the added creek basins. These data were used for the areas of the lake and the drainage basins before and after modification. The volume of the lake after modification is estimated here by multiplying the mean depth of Barnett et al. and Watson by the surface area of NSSWD. For the diverted creeks, only 80% of the flow is channelled into Maxwell Lake, because the initial autumn flushes are high in phosphorus and are not collected (Watson 2006a).

Areas of drainage basins

The sizes of drainage basins were not included on the survey sheets of the B.C. government lake surveys. Therefore, basin sizes were adopted from reports that appeared to be best documented and reliable.

In the following descriptions, the same meaning is given to "drainage basin", "basin" and "watershed". The size of the lake(s) is/are included in the basin size, unless otherwise stated. The values given in Table 1 for each of the Cusheon chain of lakes (Roberts, Blackburn and Cusheon) include the basin(s) of any upstream lakes. The basin areas are "flat" ones, that is, the areas that would be seen from above, or measured on a map. In other words, the values do not include the extra areas which would be contributed by land that is sloping. The flat areas are appropriate because the amount of precipitation falling on the basins is also governed by horizontal flat areas, that is, the amount of rainfall intercepted by the basin is proportional to the horizontal areas, not to the sloped area. [1]

Cusheon Lake. For each of the three lakes of the Cusheon basin, estimates of basin area were provided by new measurements made on computer-drawn contour maps by Brett Korteling, the G.I.S. coordinator in the Victoria office of Islands Trust (Korteling 2006). Korteling estimated 850.7 hectares (ha) for the total area of basin, down to the outlet of Cusheon Lake. Earlier statements of area were smaller, at 724 hectares (Watson 1995, Holms 1996). Korteling's estimates of the individual sub-basin areas were 119.9 ha for Roberts Lake, 510.8 ha for Blackburn, 214.5 ha for Cusheon, and 220.0 for Cusheon Creek downstream of Cusheon Lake. A map of the three sub-basins is shown in the Management Plan (CWMPSC 2007).

Later, Grange (2008a) made a definitive measurement of the whole basin down to and including Cusheon Lake, by walking the perimeter with global positioning devices. The Grange estimate

[1] Korteling (2006) made a second set of determinations for the land areas in the Cusheon watershed, by allowing for the extra areas resulting from slopes of the land. This was done by a computer program which considered the contours. These slightly larger areas are, for the Roberts sub-basin 124.4 ha instead of 119.9 for the "flat" area, for the Blackburn sub-basin 524.5 ha instead of 510.8, the Cusheon sub-basin 223.7 ha instead of 220.0 and downstream Cusheon Creek 222.4 ha instead of 214.5.

was very close to the earlier one of Korteling, being only 1.5% smaller. The Grange value is adopted here. From inspection of the respective maps, the reduced area seemed to lie mainly in the Blackburn sub-basin. Accordingly, the difference of 12.1 ha has been subtracted from the Blackburn drainage estimated by Korteling. The corrected values are shown in Table 2.

Table 2 Land and lake areas in the Cusheon watershed, determined by Korteling (2006). These are "flat" areas, as seen on a map. See footnote no. 1 for values which include the extra areas resulting from slope of the land.

Sub-basin	Area in hectares		
	Land	Lake	Total
Roberts Lake	116.5	3.44	119.9
Blackburn Lake	495.6	3.08	498.7
Cusheon Lake	193.1	26.9	220.0
subtotal, 3 sub-basins	805.2	33.42	838.6
Cusheon Creek	214.5	--	214.5
watershed total	1019.7	33.42	1053.1

Ford Lake. McKean (1981) reported 780 hectares and that value has been adopted. It apparently included the lake although that is not absolutely clear; McKean said it is for the "watershed". The same value was used by Barnett et al. (193) and Watson (1995).

St. Mary Lake. A basin area of 707 hectares was reported by Nordin et al. (1983). They estimated 525 hectares without the lake, and 707 hectares with it. The same value was used by Barnett et al. (1993), Watson (1995) and Holms (1996). Hamilton (1998) estimated watershed area using a planimeter on 1969 maps of B.C. Lands, Forests and Water, and obtained a value that was less than 2% larger (720 hectares) than the area of Nordin et al. (1988).

Grange (2008b) ground-truthed the St. Mary basin and estimated 689.8 ha, only 1% smaller than the earlier estimate of Nordin et al. The Grange measurement is used here.

Blackburn Lake. Korteling (2006) estimated 630.7 hectares for the total upstream basin of Blackburn Lake (i.e., including the Roberts basin). McKean (1981) reported 620 hectares and Watson (1995) used that value. It is not certain whether McKean included the lake (Adrains 6.2 km^2 A) but in any case the lake area has only a small influence on the total.

As indicated above, 12.1 ha was subtracted from Korteling's earlier estimate for Blackburn, yielding a value of 618.6 ha for the total upstream basin. That value is used here (see Table 2), and conforms with the definitive survey of Grange (2008a).

Stowell Lake. McKean (1981) estimated the basin at 389 hectares and that value is used here. The same number was used by Barnett et al. (1993) and Watson (1995).

Bullocks Lake. McKean (1981) estimated the basin at 212 hectares and that definitely includes the surface of the lake (A... the outlet drains 212 hectares ...@). McKean=s value is used here and was also used by Barnett et al. (1993) and Watson (1995).

Weston Lake. Nordin (1986) estimated 170 hectares; that number is adopted here and was used by Barnett et al. (1993) and Watson (1995).

Roberts Lake. Korteling (2006) estimated 119.9 hectares for the Roberts Lake sub-basin and that is used here, with 116.5 hectares for the land only (Table 2). No other reports of area have been found. This area was considered to be unchanged by the ground-truthing of Grange (2008a)

Maxwell Lake. An area of 114.5 hectares is used by the North Salt Spring Waterworks District (NSSWD) for the Maxwell watershed (Watson 2006a), and that is taken here as the original or "natural" size. Two creeks (Rippon and Larmour Creeks) have been diverted into the lake, with their basins surveyed as a total of 102.4 hectares, so the "modified" basin is 216.9 hectares. Those values are adopted here. (It must be noted that only 80% of the added creek basins can be considered as effective in channelling water to the lake, since NSSWD collects only 80% of the runoff water (Watson 2006a). The first autumn flushes are high in phosphorus, and NSSWD does not divert those flushes into the lake.)

Earlier estimates of basin area were similar. Nordin et al. (1982) reported a basin area of approximately 120 hectares, while Barnett (1993) and Watson (1995) list 117 hectares. Hamilton (1995) estimated the land area as 88.2 ha, which when added to the lake area, provides an area of 115.2 ha for the whole basin, very close to the area being used here.

Rain and snowfall

Precipitation is relevant to this study because it was used to estimate the runoff into the lakes (see below). Records of precipitation were found for eight locations on Salt Spring Island, many of them partial records in various reports, as shown in Table 3. An average value for the island was calculated from values at seven locations which had substantial sequences of records since 1975. Records from before 1975 were not used for the average, even if they were from a long historic series, because an estimate of "recent" precipitation was desired.

Table 3. **Reported yearly precipitation at five locations on Salt Spring Island.** Records in bold type were designated as characteristic of certain watersheds and used to calculate an average for Salt Spring Island. * An asterisk indicates that "water years", October 01 to September 30, were used for that record.

Location	Operator	Time period	No. of years	Mean yearly precipitation (metres)	Citation
Vesuvius	Env. Canada	**1951-80**	**29**	**0.909**	Barnett et al. (1993)
St. Mary Lake	NSSWD and Env. Canada	**1976-2005** 1976-2003 1976-93 1984-93 1977-81	**30** 28 17* 9 5	**0.979** 0.961 0.935 0.856 0.971	Watson (2006b) Env. Canada (2006) Hamilton (1995) Hodge (1995) Nordin et al. (1983)
Mansell Rd	Env. Canada	**1975-2003** 1976-93	**29** 18	**0.937** 0.916	Env. Canada (2006) Hamilton (1995)
"Saltspring"	Env. Canada	1893-1977	83	0.992	Hamilton (1995) and Env. Canada (2006)
Ganges	Env. Canada	**1976-93** 1951-80	**17*** 30	**0.916** 1.065	Hamilton (1995) Barnett et al. (1993)
Douglas Rd	Robert Aston	**1977-2005**	**29**	**0.980**	Aston (2006)
Cusheon Rd	Env. Canada	**1977-99** 1976-93	**22** 17*	**1.037** 0.964	Env. Canada (2006) Hamilton (1995)
Maxwell Lake	NSSWD	**1978-2005** 1976-93	**28** 17*	**0.958** 0.921	Watson (2006b) Hamilton (1995)
Salt Spring Island, average of seven locations				0.959	

Several comments can be made on the contents of Table 3. Some reports which list precipitation do not give the exact locations (the Saltspring, Ganges and Vesuvius locations have only general latitude and longitude to the nearest minute.). Most of the records were sponsored by Environment Canada or the North Salt Spring Waterworks District. Private records were obtained from Robert Aston for Douglas Road, which is just southeast of the village of Ganges, near the start of Beddis Road. Mr. Aston made meticulous measurements of weather for three decades (Aston, 2006). The location is about 2.4 km north of the centre of the area draining to Cusheon Lake. Environment Canada (2006) had a weather station at two successive locations on Cusheon Lake Road near Cusheon Lake, 2.7 and 1.3 km easterly from the centre of the Cusheon Lake drainage basin.

Table 3 shows some variation from place to place on the island, and also shows appreciable variation for different periods at the same location. As stated above, the choice made here to characterize a given location, was the record showing the longest run of years starting in 1975 or later. Those selections are shown in bold in Table 3.

Precipitation at the most appropriate location was assigned to the various lakes. For Roberts, Blackburn, and Cusheon Lakes, the average at Douglas Road (0.980 metres of precipitation) was selected instead of the Cusheon Road data, primarily because of the apparent reliability of the information from Douglas Road. I have seen the original records, the collecting equipment, and talked to Robert Aston about procedures, and concluded that the measurements were precise, regular and fastidious. The Environment Canada records for Cusheon Road do not necessarily inspire confidence, since the totals for thirteen of the twenty-two years are marked as “Estimate”, including one marked as “Incomplete”. The Douglas Road site is at a similar distance from the centre of the Cusheon Lake basin, and closer to the upper half than is the Cusheon Road site. In any case, the long-term average at Cusheon Road is only 5.5% higher than the average for the same 22 years at Douglas Road (Sprague 2007b), and the correlation coefficient between the two sets of yearly data is 92.8% which is good.

The Maxwell record was used for that lake. The average for St. Mary Lake was used for that lake and also for Bullocks Lake, which is fairly close by. For Ford Lake, the average rainfall at Cusheon Road was used, since it is the closest to that lake. For the other two lakes, Stowell and Weston, the Salt Spring average from Table 3 was used.

Evaporation

An estimate of evaporation from the surface of lakes is needed, if it is desired to calculate an overall “water budget” and the outflow from a lake. The most recent and appropriate estimates have been made by Watson (2006b). From temperature records, he calculated the recent evaporation from the surface of St. Mary Lake as 0.713 metres of water per year, and from Maxwell Lake as 0.585 metres. The estimates are based on temperature records from 1976 to 2005. The difference in evaporation at the two lakes results from cooler temperatures at Maxwell, which is at much higher elevation. The estimates are derived from evaporation and temperatures measured at Saanichton, at the Department of Agriculture field station. The theoretical basis for the calculations is explained by Hamilton (1995, 1998) who estimated evaporation of 0.673 and 0.658 for the two lakes, based on earlier and shorter periods of temperature records.

Watson=s values for the two lakes are accepted here. The evaporation of 0.713 metres per year for St. Mary Lake is used as the best estimate for other lakes on Salt Spring since their elevation is similar. This value is used for calculating runoff at the three lakes in the Cusheon chain (see below).

Runoff from precipitation and the resulting yearly inflow to lakes

This purpose of this sub-section is to estimate a *runoff factor* for Salt Spring Island. The runoff factor is defined as *the proportion of rain and snowfall which runs off the land and into creeks and lakes*. The precipitation that does not run off would include water that evaporates from the land, transpires from trees, and sinks into soil to replenish groundwater.

Having a value for the runoff factor, it is possible to calculate the inflow of water to any of the island's lakes. The precipitation in that area (per year) is multiplied by the runoff factor to obtain the amount of water flowing off one square metre of land. That is multiplied by the number of square metres in the drainage basin, to obtain the estimated yearly inflow to the lake. Previous parts of this report have provided areas of drainage basins and amounts of precipitation.

In this report, the runoff factor is estimated as the average of eleven estimates based on pre-existing technical reports for Salt Spring watersheds. In most cases, the estimates of the original author are adopted.

Several simplifications are involved in this estimation of a runoff factor. A major simplification is estimating a single average runoff factor for all Salt Spring watersheds. In truth, the proportion of rainfall that ran off would undoubtedly vary with different types of soil and different kinds of vegetation covering that soil. Making allowances for such differences was not feasible, and it might not be a major discrepancy. Another simplification is providing a single overall factor for the calendar year. This is legitimate since all the other calculations are on a yearly basis. (Runoff would differ with season depending on the wetness of the soil, severity of a rainfall event, etc.)

Calculations for some of the lakes involve another minor simplification because they are based on the total drainage basin including the lake. Precipitation falling on the lake=s surface is thus included as part of the "inflow" to the lake. That is appropriate except that it fails to consider the difference that 100% of direct precipitation enters the lake, while only part of precipitation falling on land reaches the lake. This approach also neglects evaporation from the lake surface. However, the result is approximately correct since the land runoff is about half the precipitation, and that is similar in magnitude to the evaporation, so the two items roughly balance each other.

For the three lakes in the Cusheon system, calculations are more precise because they add in the direct precipitation falling onto the lake, and subtract the evaporation from the lake. The calculations for the three Cusheon lakes confirm the negligible effect of the simplification, because there is less than 1% difference between the two kinds of estimates.

In some of the eleven reports listed below, the authors made a direct estimate of land runoff by measuring the amount of water entering the lake from creeks, and therefore used a basin size that included only the land, not the lake itself.

To repeat, the purpose of the following calculations is to generate an average value for the proportion of rain and snowfall that runs off the land on Salt Spring Island. Observations previously made by others are used to obtain a general average for Salt Spring. (Calculations below, and elsewhere in this report, carry more significant digits than warranted, through the initial stages. Final values in the body of the report are rounded off appropriately.)

(1) Runoff at St. Mary Lake, empirical observation. Nordin et al. (1983) measured an inflow of 3,030,000 cubic metres per year in feeder creeks, and carefully examined data for characteristics of the watershed. The drainage basin without the lake area was estimated as 5,250 hectares or 5,250,000 square metres. Dividing those two values provides a runoff factor of 0.57714 metres, i.e. 0.577 metres of water running off one square metre of land during a year.

The rainfall for the basin at the time of the survey by Nordin et al. (1983), was 0.971 metres. Accordingly, the proportion [runoff / rainfall] = (0.57714) / (0.971) = 0.59438.

(2) Runoff at St. Mary Lake, mathematical formula. Nordin et al. (1983), also developed a general mathematical relationship for runoff to St. Mary Lake in relation to the precipitation. The formula is *[precipitation in millimetres minus 500]* divided by 1,100. The average rainfall for St. Mary Lake (Table 3) is 0.979 metres or 979 millimetres. Substituting that in the formula produces an estimate of the runoff factor as 0.43545.

(3) Runoff at Cusheon Lake, mathematical formula. Nordin et al (1983) developed a separate formula for Cusheon Lake, because it had more data for measured runoff from the lake. The formula is *[precipitation in millimetres minus 340]* divided by 1,100. The average precipitation for that watershed is taken here as 980 millimetres (the value of Aston (2006) as shown in Table 3). From this, the estimated runoff factor is 0.581818.

(4) Runoff at Maxwell Lake. The net inflow in an average year was estimated as 561,000 cubic metres by Nordin et al. (1982). They used a 30-year average of precipitation from a nearby location, of 1.0264 metres/year. They estimated the basin size as 120 hectares or 1,200,000 square metres. Accordingly, the proportion *[runoff / rainfall]* = [561,000] / [1.0264 x 1,200,000] = 0.455475.

(5) Runoff to St. Mary Lake using "water budgets" (inputs and outflows). Hamilton (1998) calculated runoff factors around St. Mary Lake over 17 years, using monthly water budgets. He used a value of 0.9814 metres as the annual precipitation. The runoff estimates ranged from 0.292 to 0.637, and averaged 0.48370.

(6) Runoff to St. Mary Lake derived from "current" conditions. Watson (2006b) estimated a runoff factor for "current" conditions (i.e. 2005) and an "average water year". He developed his estimate from the data of Hamilton (no. 5 above) and analyses of trends in temperature and rainfall. Thus it uses a set of past data to estimate a most-recent average condition. His value for a current "average year runoff factor" is 0.385.

(7) Runoff to Maxwell Lake using "water budgets". Hamilton (1995) carried out similar calculations to item (5) for Maxwell Lake. He used monthly water budgets over 16 water-years starting in 1977 and ending in 1993. A value of 0.921 metres was adopted as the annual precipitation. The runoff estimates ranged from 0.255 to 0.562, and averaged 0.408.

(8) Runoff to Maxwell Lake derived from "current" conditions. Watson (2006b) estimated a

runoff factor for "current" conditions (i.e. 2005) and an "average water year". In similar fashion to item (6) above, he developed his estimate from the data of Hamilton (no. 7 above) and analyses of trends in temperature and rainfall. Thus the estimate uses a set of past data to calculate a most-recent average condition. His value for a current "average year runoff factor" is 0.42.

(9) Runoff to Cusheon Lake using "water budgets". Hamilton (1995) calculated runoff factors around Cusheon Lake, using the same techniques as in items (5) and (7). He calculated monthly water budgets for the same years as in (7). A value of 981.4 millimetres was used as the annual precipitation, essentially identical to the value of Aston (2006) that is adopted in the present report. The runoff estimates ranged from 0.324 to 0.669, and averaged 0.478.

(10) Runoff in the Cusheon watershed by calculation. A combination of information from different workers can be used to estimate the runoff for the land draining into the 3-lake Cusheon system. The yearly average outflow has been measured by Barnett et al. (1993) as 116 litres/second which is 3,660,700 cubic metres/year. It was decided above to use rainfall of 0.980 metres (Aston 2006) for this area. The total upstream drainage area of land is 8,173,900 square metres, and lake areas total 334,200 square metres (Tables 1 and 2). The yearly evaporation rate from the surfaces of the lake is estimated as 0.713 metres by Watson (2006b). (The total yearly evaporation is used in these calculations, because any water that evaporates does not contribute to the yearly outflow of Cusheon Lake.)

Using those values, the runoff factor can be obtained by the following steps. (a) The outflow of Cusheon Lake which comes from the land and not from the precipitation falling on the lake would be *[outflow measured by Barnett et al. (1993)]* minus *[the rainfall per year multiplied by the area of lakes]* = 3,333,184 cubic metres. (b) The measured outflow from the lake should be increased by water which evaporated from the lakes. That can be calculated as the outflow from (a) plus *[evaporation rate multiplied by the area of the lakes]* = 3,571,469 cubic metres. (c) The outflow from (b), divided by the land drainage area estimates the runoff as 0.436984 cubic metres of water per square metre of land. (d) The proportion of precipitation that runs off would be the value from (c) divided by yearly precipitation = 0.44590.

(11) Runoff estimated from water supply at four lakes. McKean (1981) considered the characteristics and potential water supply from four of Salt Spring's lakes: Blackburn, Bullock, Ford, and Stowell. The following calculations are based entirely on McKean=s values, shown in Table 4.

McKean provided the size of drainage basin for each lake, and the annual runoff, respectively 3,760,000, 756,000, 4,430,000, and 2,010,000 cubic metres/year. McKean calculated those values for runoff from the rainfall and size of drainage basin, but did not give details of the calculations.

McKean=s data provide four differing estimates of the runoff factor. Because the origins of the numbers were not clearly explained by McKean, an average of the four seems appropriate. The average is 0.64628.

Table 4. Runoff and other characteristics of four Salt Spring lakes as estimated by McKean (1981).

Lake	Basin size, sq. metres	Runoff, cubic metres	Runoff, cubic m / sq. m	Precipitation, metres	Factor, runoff/pptn
Blackburn	6,200,000	3,760,000	0.60645	0.7835	0.77403
Bullocks	2,120,000	756,000	0.356604	0.8357	0.42671
Ford	7,800,000	4,430,000	0.567949	0.7835	0.72489
Stowell	3,890,000	2,010,000	0.51671	0.7835	0.65949

Average proportion of precipitation running off the land into Salt Spring lakes. There are eleven proportions calculated above. Clearly, the values differ considerably and they represent different approaches, different sets of data, and different lakes. One could argue the relative merits, validity, and weights of these estimates. Instead, they have all been accepted and averaged to yield a single runoff factor.

The estimates above, in order of magnitude, are 0.385, 0.408, 0.42, 0.44590, 0.43545, 0.45548, 0.478, 0.48370, 0.58182, 0.59438, and 0.64628. **The average of the eleven values is 0.484099,** rounding to **0.484** or approximately **0.48**.

Despite the range of individual values, the average is very robust if extremes are cast out. That is, the average remains 0.48 if the highest and lowest values are rejected, and changes only slightly to 0.47 if the two highest and two lowest values are rejected.

The value of 0.48 (or 48%) is adopted as the proportion of rain and snowfall which runs off the land into creeks and lakes, for any given drainage basin on Salt Spring Island. (A value of 0.484 has been used in calculations, before rounding.)

The estimated runoff proportion of 0.48 seems to be in an appropriate range, when compared to estimates of Truscott (1981). He modelled winter runoff for six lakes on Salt Spring Island, with estimates ranging from 0.35 to 0.61 metres of runoff. **The average of 0.497 metres is less than 3% different from the value derived here, providing a reassuring comparison**. However, Truscott=s estimates were not included as data for the calculations given above, because they were theoretical values based on a model, and also because they were based on only six months of winter runoff which made them difficult to interpret. Reimer (2003) used the mathematical model of Nordin (item 2 above) to estimate the runoff at St. Mary Lake, and produced a value indicating that 41% of precipitation ran off into Duck Creek, a value close to the 41% of Nordin, as would be expected.

Final estimates of runoff into lakes

Estimating the runoff to each lake is relatively simple, based on the values calculated above. For a given lake, the drainage basin in square metres (shown in Table 1) is multiplied by the rain and snowfall for that area (Table 3) to produce the total amount of precipitation falling on the watershed. That is multiplied by the runoff factor of 0.48 (actually using 0.484) to produce the estimate of runoff entering the lake. The result is the value shown in column 6 in Table 1. As mentioned previously, the estimate for Maxwell Lake includes only 80% of the runoff from the added (diverted) creeks.

The values assigned for precipitation at the various lakes were taken from Table 3 as follows:

- St. Mary and Bullocks Lakes -- 0.979 metres from the records at St. Mary Lake (Watson 2006b)
- Cusheon, Blackburn and Roberts Lakes -- 0.980 metres from a station close to the centre of the three-lake system, as reported by Aston (2006)
- Ford Lake -- 1.037 metres from the closest records at Cusheon Lake Road, on the website of Environment Canada (2006)
- Maxwell Lake -- 0.958 metres from records tabulated by Watson (2006b)
- Stowell and Weston Lakes -- 0.959 metres, taking the average value for Salt Spring Island (Table 3), since no nearby weather records are evident.

It was also pointed out previously that the calculation for most lakes involves a slight simplification since it includes runoff from precipitation falling on the whole watershed including the lake, and excludes evaporation from the lake. However, the two items balance each other, approximately. The simplification is estimated to result in an error that is less than 1%.

This simplification was avoided for the 3-lake chain in the Cusheon system, where calculations allowed for direct rainfall and evaporation to and from the lakes. The estimates obtained in Table 5 (below) were adopted and used in Table 1 at the start of this report. The details of calculations for runoff through the Cusheon Lake system are given in the following Table 5.

Table 5. Estimated natural flows of surface water for the Cusheon basin.
This assumes no withdrawal of water by humans, a 29-year average rain and snowfall of 0.980 metres (Aston, 2006), a precipitation runoff factor of 0.484, and evaporation of 0.713 metres from the lakes during each year. Calculations are in metres, square metres and cubic metres.

		Cubic metres
Roberts Lake drainage sub-basin		
Land runoff: (116.5 ha x 10,000) x (0.980 m of rain x 0.484) =		552,583
Directly onto lake = (3.44 x 10,000 x 0.980) =		33,712
Minus evaporation: lake area 34,400 x 0.713 m =		24,527
	Estimated outflow:	**561,768**
Blackburn Lake drainage sub-basin		
From upstream Roberts Lake:		561,768
Sub-basin land runoff: (495.6 ha x 10,000) x (0.980 m of rain x 0.484) =		2,350,730
Directly onto lake = (3.08 x 10,000 x 0.980) =		30,184
Minus evaporation: lake area 30,800 x 0.713 m =		21,960
	Estimated outflow:	**2,920,722**
Cusheon Lake drainage sub-basin		
From upstream Blackburn Lake:		2,920,722
Land runoff: (193.1 ha x 10,000) x (0.980 m of rain x 0.484) =		915,912
Directly onto lake = (26.9 x 10,000 x 0.980) =		263,620
Minus evaporation: lake area 269,000 x 0.713 m =		191,797
	Estimated outflow:	**3,908,447**
Estimated outflow converted to yearly average litres/second =	123.85 L/sec	
Observed mean annual outflow for 1970-1992 (Barnett et al. 1993) =	116.0 L/sec	

Footnote giving corrected values. According to records for Victoria, the period of 1970-1992 which produced the measured outflow of 116 L/sec, had rainfall that was 2.6% lower than in 1977-2005, the period used in the present calculations. Correcting Barnett=s flow measurement upwards by 2.6% results in a mean annual measured flow of 119.0 L/sec.

Also, the outflow estimated here should be decreased by the withdrawals for human use, in order to compare it with Barnett=s observed measurement. Potential withdrawals have been estimated as 138,024 cubic metres per year (Sprague 2007a). Subtracting that amount produces an estimated outflow of 119.48 L/sec.

The estimated outflow corresponds almost exactly with the corrected outflow measured by Barnett, which is either excellent confirmation of the estimate in Table 5, or else an amazing coincidence.