Gooding
Hydrology

TSOLUM RIVER
Flow Augmentation
In the Tsolum Watershed

For the
Tsolum River Restoration Society
Courtenay, B.C.

By
Dave Gooding, P.Eng.
Gooding Hydrology
Saltspring Island

December 2007

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Executive Summary

Natural (unaugmented) flows in the Tsolum River during August and early September are often less than 5% of the Mean Annual Discharge (MAD), occasionally under 1% MAD. Augmentation from Wolf Lake reservoir currently attempts to provide flows of 10% MAD in the lower 18 km of the Tsolum River, below Headquarters Creek. Locations for impounding water to provide flows closer to the 20% MAD range, for the lower reach, and a reach-appropriate 20% MAD for the extensive upper Tsolum reaches as well, are investigated in this report. A priority in the study is increasing amount of, and access to, coho rearing habitat.

The largest and most cost effective storage location for water to further augment flows in the lower Tsolum is Wolf Lake, and any solution should include additional storage on that Lake, to be released through Headquarters Creek. The option of adding storage of over a meter on Wolf Lake, and diverting the additional water through an excavation from the head of the lake to Constitution Creek, is investigated. This would provide increased flows in an additional 7.4 km of Tsolum mainstem, and through a large wetland complex on lower Constitution Creek, however the excavated diversion channel would be 0.6 km long and up to 9 m deep.

Five lakes in the upper watershed, and a site at the top end of the upper Tsolum ravine, were evaluated for potential storage volumes, works needed to develop them, benefits provided, and the impacts of flooding of various depths, to both wetlands habitat and forest land base. Individual options are discussed in the body of the report, with a summary sheet provided as Appendix 6.

Hell Diver Lake is presented as an option for local augmentation, of its wetland associated tributary channel down to the upper Tsolum. Of the other five sites, only the site at the top end of the Tsolum ravine (Regan-Blue Grouse Confluence) has the potential for sufficient storage at a single site for fully augmenting flows through the entire mainstem down to Headquarters Creek, however a 20 m impoundment would be needed, a major work.

Benefits in fish habitat increases have not been quantified. Appropriate and easily accessible locations for required stream habitat assessment, to quantify the benefits of any augmentation, are identified and mapped.

Points for the Steering Committee to consider when deciding on which locations, or combinations of locations, to pursue further are presented in the individual site discussions and in the 'Recommendations' section.

1.0 Project Location

The Tsolum River drains from the west side of the Forbidden Plateau, west and northwest of Courtenay, on east central Vancouver Island. The mainstem Tsolum originates from Blue Grouse Lake, at around 420 m elevation, flowing for 7.5 km east through a high ravine at gradients from 3.5% to 20%, down to around 200 m elevation. The Tsolum mainstem then turns to flow in a southeasterly direction for 30 km, in a low gradient channel along the base of the mountain, entering the ocean through Courtenay. A watershed map showing main tributaries is given below.

Figure 1: Tsolum River

1.1 Background to Study

Late summer low flows in the Tsolum River main channel limit growth, size, and numbers of resident fish such as rainbow and cutthroat trout, available rearing habitat for coho fry, and access to spawning for early salmon, particularly pink salmon. The Tsolum River Restoration Society (TRRS) obtained a Pacific Salmon Foundation grant to conduct a hydrologic feasibility study to determine potential sources for increasing flow augmentation in the Tsolum River, engaging Gooding Hydrology for this study. Particular focus of this study is intended to be coho salmon enhancement by flow augmentation.

Augmentation of August 15 to September 30 low flows is currently done for the Tsolum River from Wolf Lake, through Headquarters Creek. The current use of Wolf Lake for augmentation is three feet (0.91 m), or 144 hectare meters. Flow augmentation is released as necessary from Wolf Lake to provide 30 to 35 cfs, (0.85 to 0.99 cubic meters per second, CMS), total flow at the WSC gauge 08HB011 Tsolum R near Courtenay, located below the Portuguese Cr and above the Puntledge River confluences. The released storage is typically up to 15 cfs, (0.42 CMS), increasing flows in Headquarters Creek and the lower 18 km of the Tsolum mainstem, downstream of the Headquarters (HQ) confluence.

A flow as measured at the WSC gauge 08HB011 of 35 cfs is 9.9% MAD, and is assisting access of pink salmon to the Tsolum mainstem below HQ, and increasing resident fish production in HQ Creek. (J Minard, pers com). However, flows from HQ Creek increase flows in only the lower 18 km of the 30.5 km of low gradient mainstem Tsolum.
To significantly increase rearing productivity and access, flows during the low flow period should be augmented to at least 10% of Mean Annual Discharge, (MAD), and ideally to 20% of MAD. For the lower Tsolum River, 1985 to 2004 MAD was calculated from the WSC gauge 08HB011. MAD at this gauge was 10.1 CMS, giving a goal for augmenting flows in the lower Tsolum River up to the range of at least1 CMS, up to 2 CMS to augment to 20% MAD.

Additional water storage is needed to increase flows in the Tsolum below HQ Creek up closer to 20% MAD, and to augment flows in as much of the 12.5 km of low gradient mainstem upstream, as well as accessible upper Tsolum mainstem and tributaries upstream of HQ Cr as possible.

1.2 Consultations

A scoping and brainstorming meeting was held May 16/07 at the Puntledge hatchery, with Dave Lindsay (Timber West), James Craig (BC Conservation Foundation), Bryan Munro (DFO Puntledge Hatchery), and Jack Minard (TRRS). Main points and options emerging from that meeting included:

1. As the largest (and already controlled) lake, additional storage on Wolf Lake would be beneficial, to increase augmentation through HQ Creek.
2. The potential to divert increased Wolf Lake storage north from the head of the lake, across a low pass and into Constitution Creek, thereby augmenting the Tsolum mainstem for an additional 7.4 km, should be investigated.
3. Murex Creek sub-basin should not be utilized for storage. Water quality problems may emerge if storage there were utilized for low flow augmentation, due to ongoing, if improving, acid mine drainage in that sub-basin.
4. A source, or multiple sources, of adequate water storage in the upper Tsolum, upstream of as much as possible of the lower gradient mainstem Tsolum channel, would provide the maximum benefit to the system.

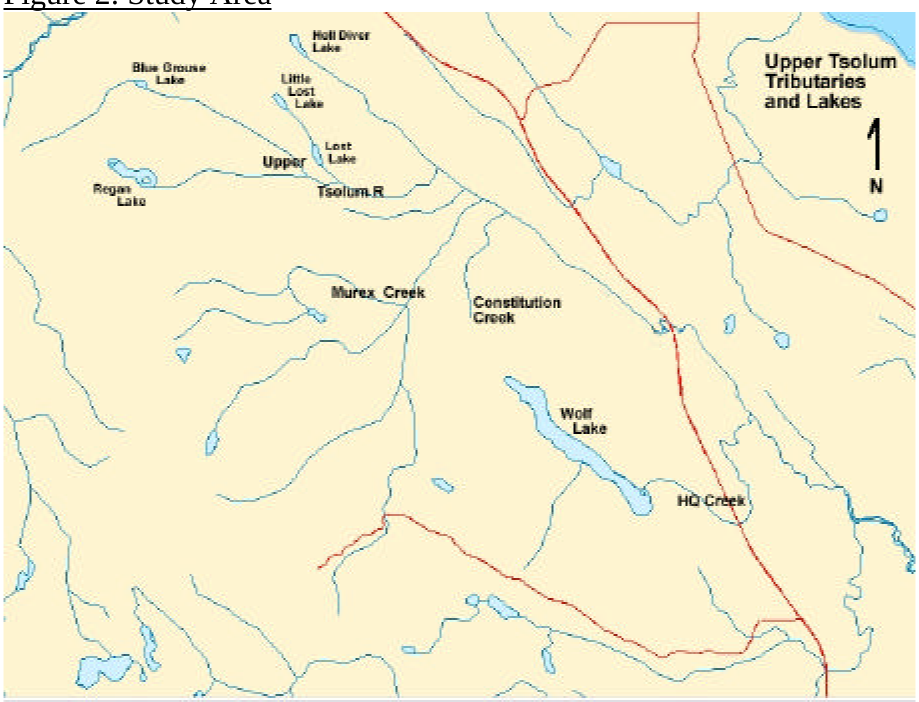
1.3 Study Scope

The entire watershed was given an overview preliminary office study. The Puntledge and Browns Rivers were excluded from further study due to the short length of mainstem Tsolum River, below their confluence with the Tsolum which would be enhanced.

The Dove Creek sub-basin, as its confluence with the Tsolum is only at km 14 of the mainstem Tsolum, 4 km downstream of Headquarters, was also only given a brief investigation. While it was excluded from this study due to its confluence with the Tsolum being relatively low in the system, it is worth noting for possible future reference for enhancement for resident Dove Creek trout, that 22 ha Anderson Lake has the topography to allow substantial storage, backed by a higher elevation watershed than that of the upper Tsolum, with greater snow accumulation. On the negative side, it has an attached wetland complex just slightly smaller than the lake, which would be impacted.

More detailed study was limited to Headquarters Creek, Wolf Lake, Constitution Creek, and all tributaries upstream of Murex Creek.

Figure 2: Study Area



2.0 Total Water Storage Needed

The volume of water storage required to increase flows by an additional 10% MAD, or 1 CMS, for 45 days, at gauge 08HB011 near Courtenay, is approximately 390 hectare meters. The impoundments created should be located such that each river reach of the Tsolum, or its tributaries, should be augmented to a flow which is in the range of 10 to 20% of the MAD *of that stream reach*, if possible. *Note that the figures given below for storage do not take into consideration losses between the reservoir and the specific stream reaches being augmented.*

2.1 Stream Channels to be Augmented

Flow augmentation needs in reaches upstream of HQ creek, to augment the upper system as well, are estimated below. This estimate is based on MAD per sq km of basin area for the three gauged locations in the Tsolum watershed, Browns, Dove, and Tsolum WSC gauges, and a graph of MAD versus basin size, for east central Vancouver Island, given as Appendix 1.

Table 1: Stream reaches, approximate drainage area, and an estimated appropriate MAD for each reach.

Reach	**Length (km)**	**Basin Area (km^2)**	**Estimated MAD (CMS)**	**10%MAD (CMS)**	**U/S Storage to augm by 10% to 20% MAD (ha-m)**
Tsolum: 5th St to HQ	18.1	258	10.1	1.0	390
Tsolum: HQ to Constitution	7.4	92	3.6	0.36	145 to 290
Tsolum: HQ to Murex	2.4	90	3.5	0.35	140 to 280
Tsolum: Murex Cr to Hell Diver Confluence	1.35	45	1.75	0.18	70 to 140
Hell Diver Lake to Tsolum confluence	4.1	6.3	0.25	0.025	9.5 to 19

For purposes of the study, the 5th Street bridge in Courtenay was taken as kilometer 0 in channel length measurements. The Tsolum mainstem is taken as originating in Blue Grouse Lake. Unnamed upper Tsolum creeks are designated by the lake name, i.e. the stream from Regan Lake is called Regan Creek

Hell Diver Creek is the only major low gradient tributary to the upper Tsolum River, an extension of the low gradient mainstem Tsolum, which extends from the Tsolum-Hell Diver confluence downstream to the ocean. The Upper Tsolum from the Hell Diver Creek confluence upstream gradually increases in gradient, with two locations over its 7.5 km length at around 20%, however the majority is at gradients of 3% to 6%. A more detailed table of Tsolum mainstem stream reaches, lengths, average gradients, and channel widths (where measured), is given as Appendix 2.

A detailed assessment of the increases in available stream and wetland fish habitat, in each of the reaches where augmenting is proposed, would need to be performed for an environmental impact assessment of water storage proposals. Some easily accessed stream habitat assessment locations are given in Appendix 3, which includes a brief description and photo of the channel, and the access. Locations actually assessed would depend on storage options considered further, and consultation with DFO.

3.0 Approach to Location of Potential Reservoir Sites

The ideal reservoir location is a broad, low gradient, adequately sized basin, with a narrow outlet to dam, and slopes around the reservoir high enough to contain the raise in water level needed to develop the desired storage. These conditions are typically found at existing lakes, however a study of the contour mapping of the upper Tsolum was carried out to determine if the topography needed also existed elsewhere than at the lakes. This resulted in the addition of the "Blue Grouse-Regan confluence" option to the areas analyzed.

Field trips to all the lakes with the exception of Blue Grouse Lake were made between September and December 2007, with field survey measurements made where needed to determine the potential for water storage and scope of works required. Maps utilized for office measurements of lakes, attached wetlands, and potential reservoir areas were the 1 to 30,000 scale contour mapping supplied by Timber West.

3.1 Environmental Constraints

Storage options selected should minimize impacts to existing wetland areas adjacent to lakes. The drainage area upstream of any impoundment has to be adequate to fill the reservoir even in dry years, without significantly adversely affecting flows in the downstream reach during the filling of the reservoir over the wet season. Mean inflows to each potential storage location site are given in Appendix 4.

4.0 Discussion of Options

Table 2 below gives the open water and wetland areas of the storage locations investigated, as well as the drainage basin area upstream of the potential dam site, and calculated average inflows from November 1 to April 30, when the reservoir will be filling.

Table 2: Lake and wetland areas, wet season inflows

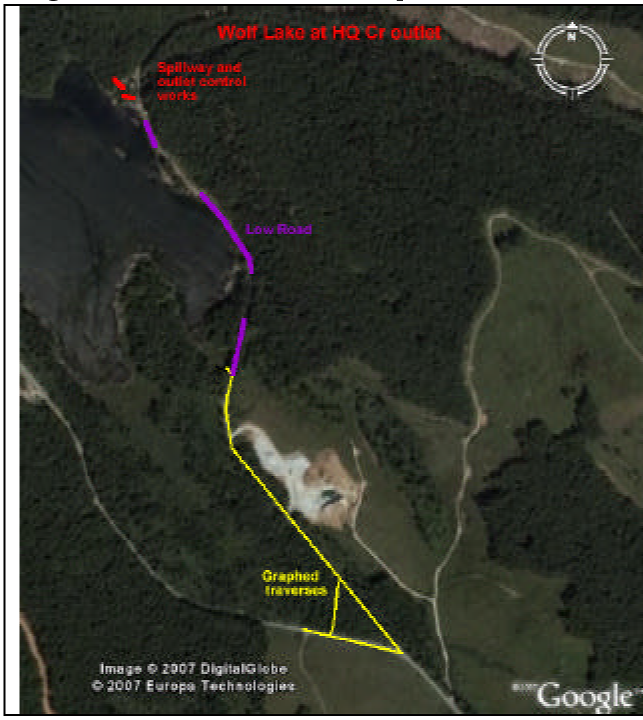
		Area of open water (ha)	Area incl. wetlands (ha)	Area of wetlands (ha)	Basin area (km^2)	Oct1-Apr30 inflow (ha-m)
1	WOLF LAKE	157	160	3	19.9	2130
2	HELL DIVER LAKE	7.5	19.2	11.7	6.26	670
3	LITTLE LOST LAKE	5.3	6.0	0.7	1.47	160
4	LOST LAKE	5.0	6.9	1.9	2.34	250
5	REGAN LAKE	18.2	20	1.8	7.47	800
6	BLUE GROUSE LAKE	4	7.5	3.5	3.56	380
7	BLUE GROUSE-REGAN CONFLUENCE	0			14.7	1570

The seven locations above, with possible storage, advantages, and disadvantages, for various levels of impoundment, are discussed individually below. A summary sheet of the all options, with heights of dams, storage created, impacts, and works needed is given as a Summary Table, Appendix 5. Order of table above, and discussions, is from downstream to upstream in the location of the tributaries' confluence with the Tsolum mainstem.

4.1 Wolf Lake

With a surface area of 157 hectares, increased storage volumes are large for a small raise in lake level. An increase of 1 meter of lake level gives around 160 hectare meters (ha-m) increased storage, a 2 m raise provides more than 330 ha-m over present storage. Two additional meters is enough water to provide additional augmentation of 8.5% MAD for the lower Tsolum (below HQ Cr), over the approximately 10% MAD currently maintained in August and September.

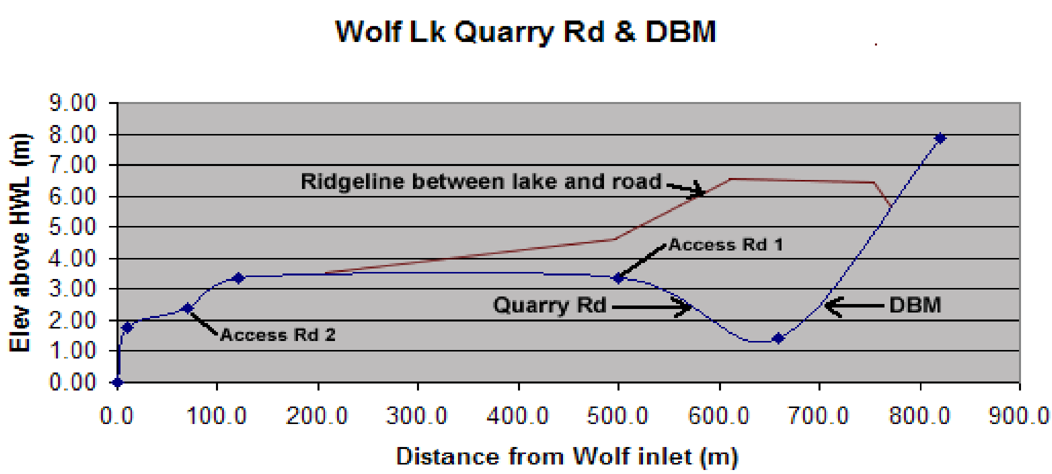
Figure 3: Wolf Lake at Headquarters Creek Outlet



To determine the additional works, (raising of roads, auxiliary dams), besides those at the outlet control structures, which might be required for 1, 2, and over 2 m raises in water level, a rough traverse of the Quarry Road, and the ridge line between Wolf Lake and the Dove Creek sub-basin, at the south-east corner of the lake, was done. This is shown as yellow lines on the Google photo to left. Purple lines mark approximate stretches of roads which would need to be raised for a 2 m lake level rise, approximately 400 m in total length. Approximately half the length of road would need raising for a 1 meter water level rise

The graph below shows the traverses marked above, showing additional road raising which would be needed for a lake raising over 2 m.

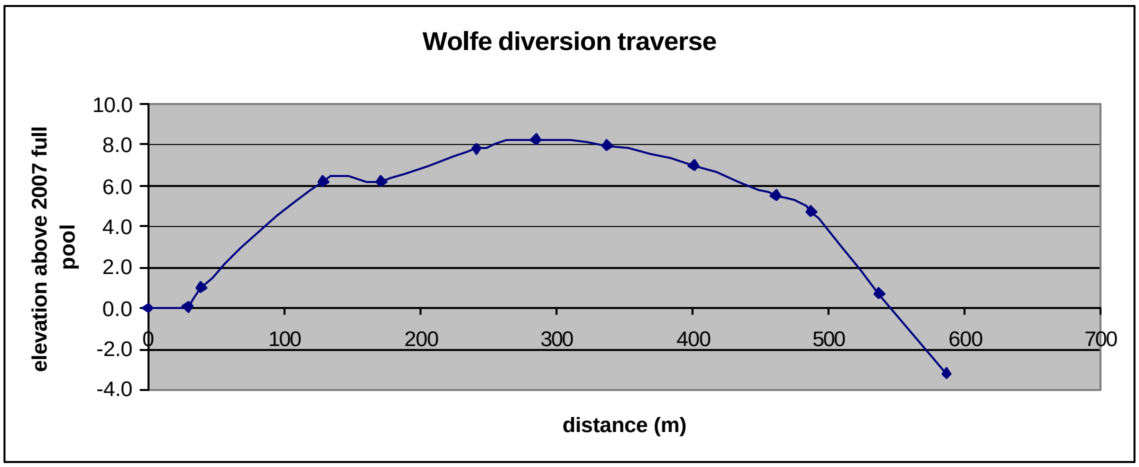
Figure 4: Quarry Road Profile



As can be seen from the graph above, a raise in the lake level of anywhere near or above 3 m would require raising the 450 m of the quarry road, or the full length between the two pit access roads. As well, a short, low auxiliary dam between the quarry road, and the ridge between the lake and the road, (around 20 m long by 1 m high for a 3 m lake raise), would be needed.

4.1.1 Diversion of storage in Wolf Lake to Constitution Creek
Diversion of additional storage in an excavated channel from the head of Wolf Lake to Constitution Creek would provide flow augmentation to the creek, extensive wetlands along 0.5 km of the lower end of Constitution Creek, and to an additional 7.4 km of mainstem low gradient Tsolum R above HQ Creek. A field survey traverse was performed from the full pool edge of water at the head of Wolf Lake, over the pass to the Constitution Creek channel, to determine the amount of material which would have to be removed to enable diversion of any increased storage in Wolf Lake to Constitution Creek. A graph of the survey, with vertical scale exaggerated, is shown below.

Figure 5: Wolf Lake to Constitution Creek traverse



A 66% grade, (1.5:1), on the excavated channel sides is assumed. Table 3 below gives the depths of cut, and volume of cut required to allow increased storage to flow, (at 0.56% grade), to Constitution Creek, for the two options of
- increasing storage by up to 2 m, allowing much of the 'top' extra storage to flow to Constitution,
- increasing storage by over 2 m, and utilizing the storage above 2 m for diversion to Constitution, in a 2 m shallower cut.

Depth to rock along the cut is unknown.

Table 3: Diversion trench to Constitution Creek

Storage Option	Length of Cut (m)	Maximum Depth (m)	Volume of Cut with 3 m bed (m^3)	Volume of Cut with 1 m bed (m^3)
Up to 2 m rise	560	9.9	72,000	56,000
Over 2 m rise	500	7.9	45,000	34,000

4.2 Hell Diver Lake

Lake outlet topography would allow a relatively short dam and outlet control structure to retain a moderate amount of storage. However, on the basis of the large amount of wetland habitat which would be impacted by raising water levels, Hell Diver Lake was dropped from further consideration as a large volume water impoundment option which could provide significant augmentation of Tsolum mainstem flows.

However, the 4.1 km reach of Hell Diver Creek, from Hell Diver Lake to the confluence with the Upper Tsolum, is low gradient, and associated with wetlands for over three quarters of its length. Coho rearing habitat could be enhanced in this 4.1 km by a relatively small impoundment at Hell Diver Lake outlet. A 0.5 km rise in lake level would store 9.5 ha-m of water, which if released over 45 days at 0.025 CMS would provide a reach specific 10% MAD augmentation of existing flows, over this 4.1 km reach. It is possible that the seasonal raising of water levels in Hell Diver Lake by up to 0.5 m would not have a severe impact on the wetlands associated with the lake, particularly if the impoundment levels were brought up gradually over a number of years, allowing vegetation regimes to shift and adjust. This would have to be looked at by a biologist for further input to the decision whether to create storage here, and how much.

Hell Diver Creek exits the lake in a short, narrow passage to a lower wetland, then drops through a small canyon just downstream of the wetland. Fish passage up this little canyon would be difficult, but it should be investigated as to whether coho get up it.

Figure 6: Hell Diver Lake, with wetlands stretching from the head of the lake at upper left.

Dam and outlet control would have least wetland adverse impacts located between the lake and lower wetland complex (red line).

Upgrading of up to 600 m of road may be necessary for access to dam site.

4.3 Little Lost Lake
This lake has good topography for storage of water, with over 80 m high steep lake side slopes. The fairly narrow outlet valley has a 20 m wide outlet 'floodplain', with 30% and 50% side slopes. Less wetland would be impacted by flooding than any of the other lakes looked at, (0.7 ha). The head of the lake topography is flatter, around 5% on average, so surface area would rise significantly with water level. The maximum impoundment depth available is limited by the height of the headwater divide to Hell Diver Lake. A 10 meter impoundment would be feasible, however more may need additional diking along the divide to Hell Diver.

A 10 m impoundment would produce an estimated 100 ha-m storage, which would provide 7% MAD augmentation at the lower Tsolum WSC gauge, and around 15% 'local' MAD augmentation for the Tsolum low gradient channel down to the HQ Creek confluence. As well, it would augment flows in the higher gradient upper Tsolum, channel, for 3 km, the majority of its length between the Hell Diver confluence and the first fish passage blockage.

However, the drainage basin is only around 1.5 sq km. Looking at monthly average inflows, (Appendix 4), the estimated average 1985-2004 October through April inflow to the to Little Lost Lake is 160 ha-m. Given that during the driest year on record at the Tsolum gauge, flows were only 46% of the average yearly flow, it would appear that during the driest years, when augmentation is most needed, a 10 m reservoir on Little Lost Lake may not fill. Volumes for lower depths of impoundment, are given in the summary table, Appendix 5.

4.4 Lost Lake
A small lake, 6.9 ha including wetlands, the valley sides along, and at the head of, the lake are tall and relatively steep. Less storage would be created by a 10 m impoundment here than at Little Lost Lake, due to the narrowness of the valley at the head of the lake. A 10 m impoundment would produce around 85 ha-m of storage, a 15 m raise would create around 140 ha-m. The drainage area is 2.34 sq km, giving an estimated average October through April inflow of 250 ha-m. On the lowest recorded year at the Tsolum gauge, this inflow would have been under 115 ha-m. In other words, to store in the range of 100 ha-m in Lost Lake, during a very dry year, would require nearly all the October-April inflow to be captured, leaving little outflow during those months.

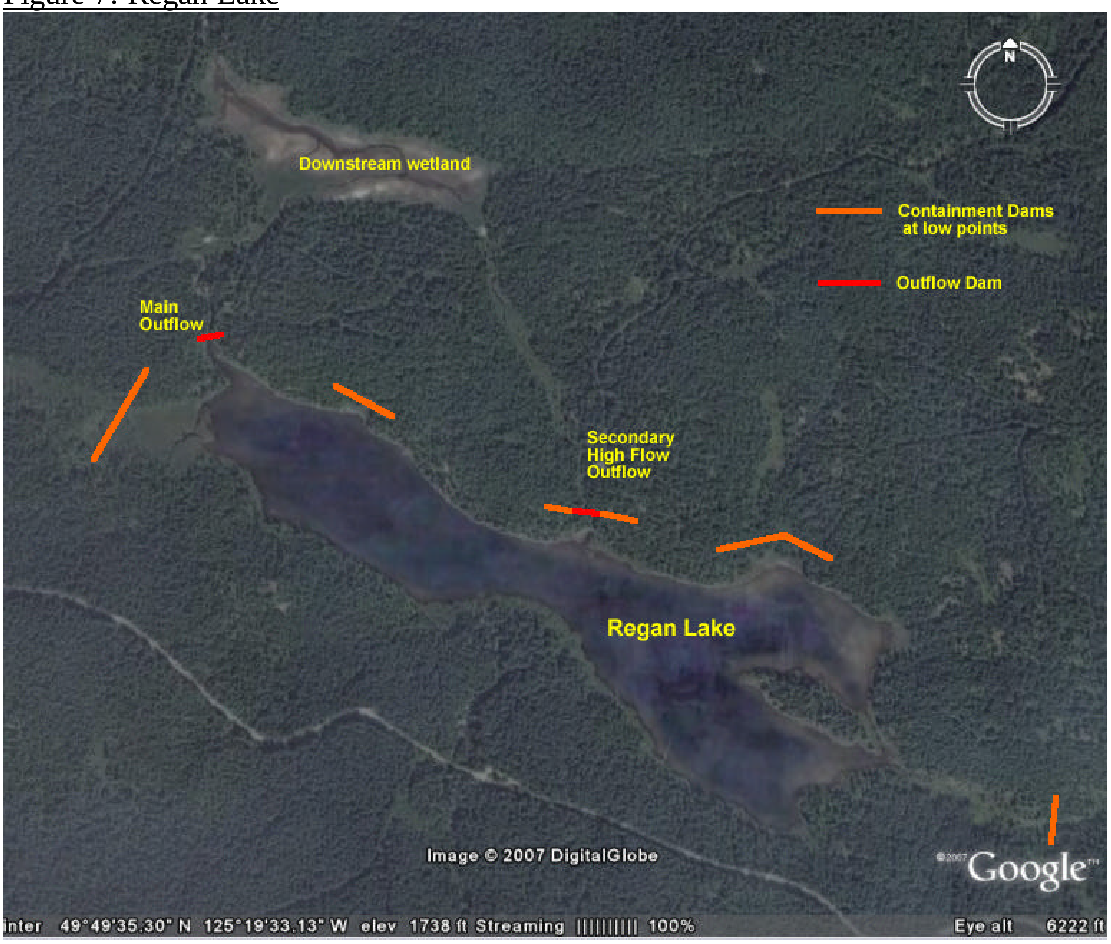
Outlet topography for dam construction is slightly less favorable than at Little Lost Lake. The valley widens just downstream, so a dam would have to be constructed across the wetlands at the outlet, requiring excavation of an unknown depth of wetland alluvial soils to get a solid base. While the floodplain at the best location is only around 20 m wide, side slopes are shallower, at 10% and 15%, requiring a longer dam. This lake also has larger associated wetlands, (around 2 ha), which would be impacted by any significant raising of lake levels.

4.5 Regan Lake

Regan Lake, at 18.2 ha (20 ha with wetlands) is larger than any of the lakes studied, with the exception of Wolf Lake, and has an adequate drainage area of 7.5 sq km, with average October-April inflow of around 800 ha-m.. However, due to the very low topography along the entire north side of the lake, the height of impoundment is very limited. Indeed, the topography is so low that during high water periods Regan Lake drains from a second outlet midway along the north side, as well as its usual water outlet at the NW corner. Raising of the lake level 3 m would create over 60 ha-m of storage. As well as a small outlet dam, this would require construction of 2 km of road, accessing the entire north and west sides of the lake, with as much as a third of that length acting as containment dikes for between 1 and 3 meters of the height of the raised lake.

Regan Lake has associated wetlands of around 2 ha which would be impacted by raising water levels, and it is unknown what the impact of cutting off the second outlet would have on the small un-named lake and wetlands just downstream, which is fed by both outlets.

Figure 7: Regan Lake



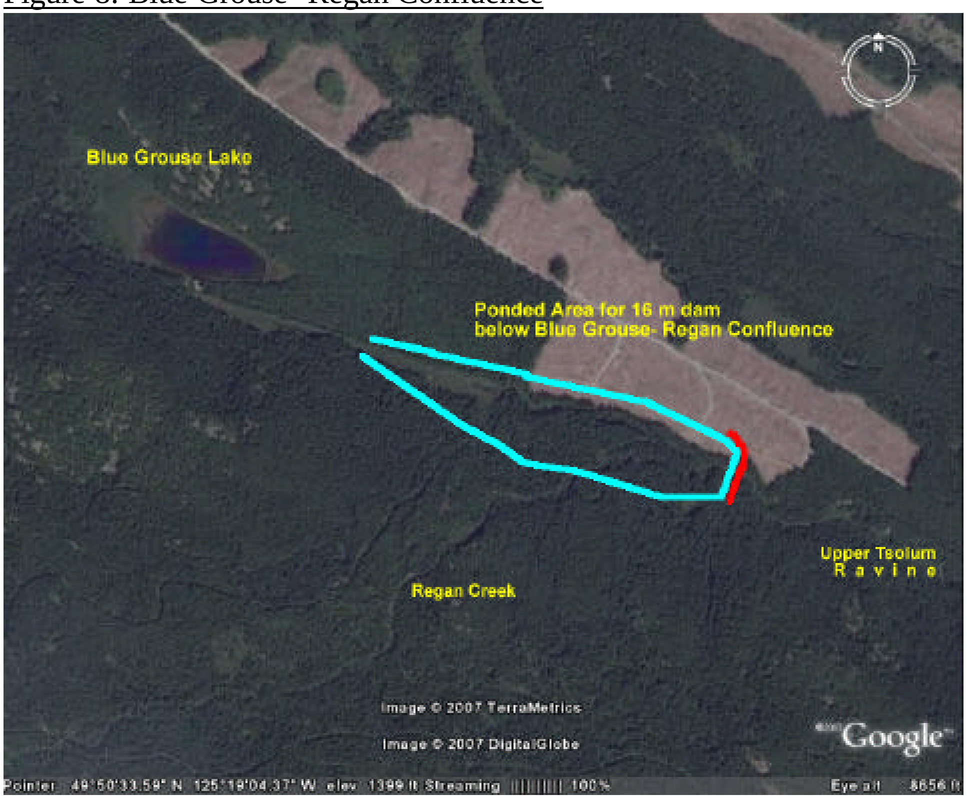
4.6 Blue Grouse Lake

Blue Grouse Lake is relatively small, 4 ha, with attached wetlands nearly the size of the lake, at around 3.5 ha, mostly at the shallowly sloping head of the lake. While the sides of the lake have adequate height for substantial storage, the head of the lake has limited height to the divides to the Oyster River and Black Creek drainages. While a 5 m raise should be possible, producing storage of around 60 ha-m, it appears from topograhic mapping that 10 m raising of water level would require auxiliary dams along the Oyster or Black Creek divides. Dam construction would require upgrading of 1 km of road. Dam length, and volume of material required, as given in the Summary Table, Appendix 5, is a very rough estimate as the topography was not viewed in the field.

4.7 Blue Grouse- Regan Confluence

A 15 m high dam, just downstream of the confluence of the Regan and Blue Grouse outflows, would create a pond on the upper Tsolum, downstream of Blue Grouse Lake, and upstream of the long ravine, of approximately 20 ha surface area, with 90 ha-m storage of water. There would be no impacts to an existing lake's wetlands or shoreline habitat, but a small impact to the narrow wetlands along the stream from Blue Grouse Lake. Each additional meter of height from that point adds over 20 ha-m of storage, to approximately 20 m height where the ponding would start to raise Blue Grouse Lake levels as well. Pond levels over 25 m would impact increasing lengths of the stream's narrow wetlands, which run for the upper 0.9 km of the 1.5 km between Blue Grouse Lake and the potential dam site. A recent road, Pigget Main (PGM) 700, runs to the dam site.

Figure 8: Blue Grouse- Regan Confluence



5.0 Recommendations

There are various combinations of locations and heights of impoundment, as listed in the Summary Table Appendix 6, which would provide adequate increased storage to augment the lower Tsolum to near 20%, and provide augmentation for the upper Tsolum at the same time. The following should be considered in the decision making on which options to pursue further:

1. At least 1 meter of additional storage should be developed on Wolf Lake. This would provide just under half of the additional 10% MAD flow augmentation needed between the Headquarters-Tsolum confluence and the ocean, with minimal road raising and magnitude of works at the outlet control structures.

2. Diversion of additional storage from Wolf Lake through Constitution Creek would augment flows in the Tsolum from the Constitution confluence down, and would also augment flows and increase water levels in the large wetland complex near the bottom end of Constitution Creek. As this large wetland is easily accessible from the Tsolum River, its value as enhanced coho rearing habitat should be considered and investigated further. Note that a diversion channel excavated only to the depth of current Wolf Lake full pool would cease operating when Wolf Lake was drawn down to its current operating range.

3. Further biological study is needed of the potential impacts to wetland habitat around Hell Diver Lake, and downstream benefits to the stream and associated wetlands habitat on Hell Diver Creek, for impoundment levels on the lake of up to 0.5 height. While not of value as a major contributor to augmenting Tsolum mainstem flows, this option has potentially high value to enhance local coho rearing habitat down to the Tsolum-Hell Diver confluence, and should be considered regardless of which mainstem options are chosen.

4. Flooding of Little Lost Lake has a minimal wetland impact, and relatively low magnitude of works, for storage of a significant amount of water. A discussion is needed with DFO, and possibly further study by a biologist, as to what percentage of the inflows to this potential reservoir could be retained from the wet season flows, in consideration of potential downstream effects on Lost Lake, and the downstream tributary to the Tsolum.

5. The Regan-Blue Grouse location has the potential for storage of up to 200 ha-m of water, and an adequate inflow to allow storage of this amount, which would provide single site full augmentation for the upper and middle Tsolum, with little wetland impact. However, a major dam (21 m high) would be needed to develop this potential.

Some of the combinations for full augmentation of the Tsolum mainstem which might be considered are;

- 160 ha-m down HQ Creek from Wolf Lake, with an additional 160 ha-m released down a diversion to Constitution Creek, and 60 to 70 ha-m from Little Lost Lake.

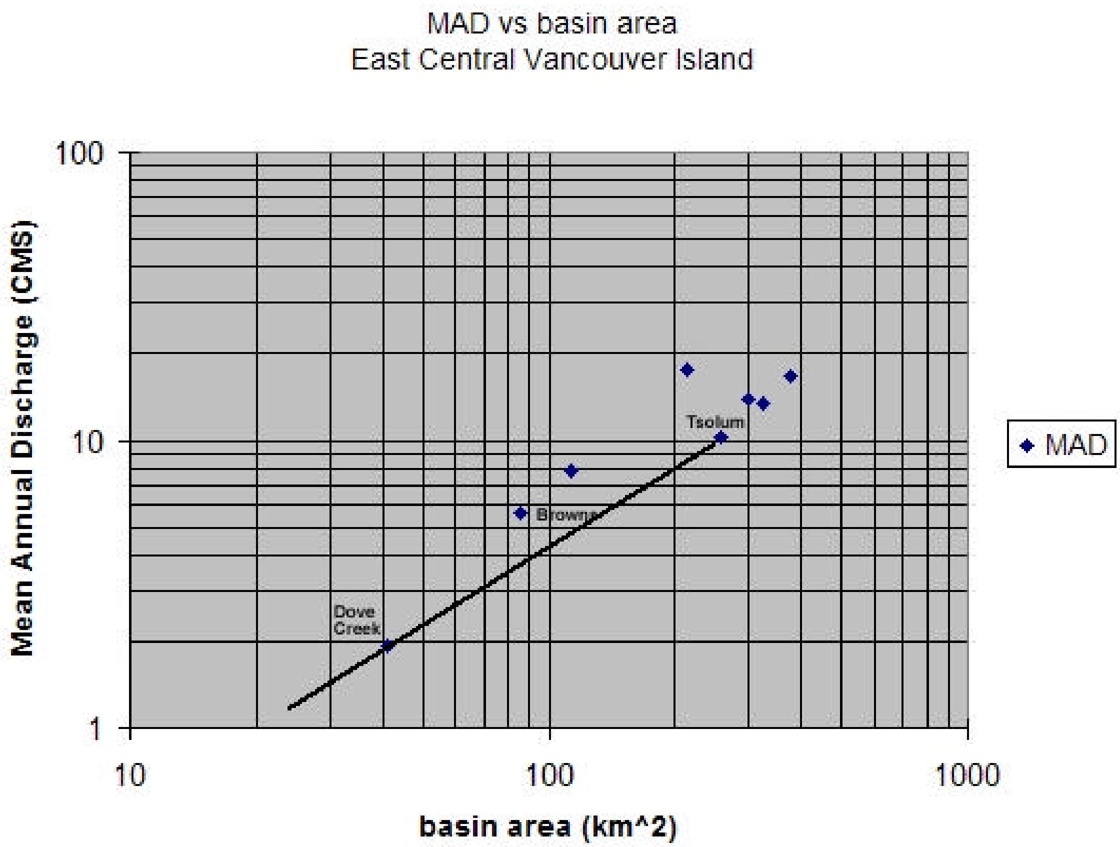
- 160 ha-m down HQ Creek from Wolf Lake, with an additional 180 to 200 ha-m from a dam at the Blue Grouse- Regan Confluence.

-160 ha-m down HQ Creek from Wolf Lake, 90 ha-m from a smaller dam at the Blue Grouse- Regan confluence, and development of combined storage of 100 ha-m on Lost and Little Lost Lakes.

As previously discussed, further study of potential storage of up to 10 ha-m at Hell Diver Lake should be undertaken, regardless of mainstem Tsolum augmentation options chosen.

Dave Gooding, P.Eng.

Appendix 1: Graph of Mean Annual Discharge verses Basin Area



Note that Browns River has a higher MAD per sq km, due to the higher watershed. Figures used to calculate the MAD for sub-basins of the Tsolum are based on the lowest mean monthly discharges per sq km at the three Tsolum WSC gauges.

Gooding Hydrology
dgooding@saltspring.com

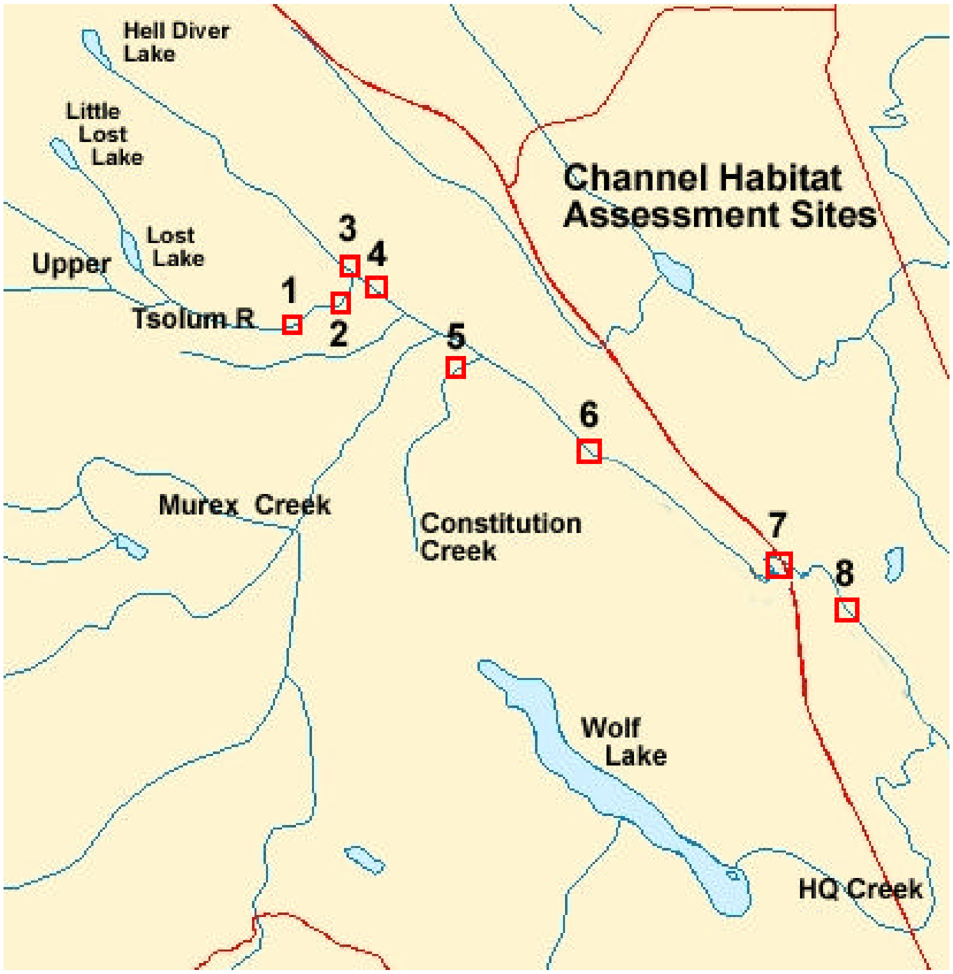
Appendix 2: Stream reaches of the Tsolum mainstem

reach	elevation top end (m)	stream length (m)	cumulative stream length (m)	average gradient (%)	channel width (m)	Comments
0	0	0	0			Tidal waters (5th St bridge)
1	20	8,140	8,140	0.25	30+	Puntledge to 20 m contour 7,140 m
2	40	3,900	12,040	0.51		Below Dove Creek
3	60	3450	15,490	0.58	30	Dove Cr at center of reach
4	80	10800	26,290	0.19	20-25	Below HQ to just above Constitution Cr
5	100	3000	29,290	0.67	15-20	Above Constit. to upper Tsol/Helldiver confl
6	120	1200	30,490	1.67	15	edge of lowlands
7	180	1500	31,990	4.00	13	
8	240	1170	33,160	5.13		
9	260	150	33,310	13.33		
10	280	100	33,410	20.00		
11	300	300	33,710	6.67		Lost Lakes confluence
12	320	380	34,090	5.26		
13	340	580	34,670	3.45		
14	360	100	34,770	20.00		
15	380	560	35,330	3.57		
16	400	500	35,830	4.00		Just below Regan confluence
17	420	1700	37,530	1.18		Blue Grouse lake

Note: For purposes of the study, the 5th Street bridge in Courtenay was taken as kilometer 0 in channel length measurements.

681 Rainbow Road, Saltspring Island, B.C. V8K 2M7 *Phone: 250 538-1869 Fax:5338-1879*

Appendix 3: Upper Tsolum Accessible Stream Habitat Assessment Sites



The above sites are representative of upper Tsolum R channel habitat to be enhanced. As procedures will have to be repeated at multiple flows, sites were selected to be easily accessible. Descriptions and access to sites are listed below.

Site #	Description	Width (m)	Slope (%)	Access route
1	Tsol bel ravine	11	3	End of Duncan Bay Main (DBM) 3500
2	Tsol ab Hell Diver	13	1.5	DBM 3520 old crossing
3	Hell Diver Cr	5	<1	DBM above crossing 500 m
4	Tsol bel Hell Diver	12	1	DBM at Tsolum crossing
5	Consitution Cr	3	1 - 3	Constitution Main (DBM 3700)
6	Tsol bel Constit	16	<1	Constitution Main (DBM 3700)
7	Tsol at Isl. Hwy	18	0.5	Inland Island Hwy crossing
8	Tsol above HQ	20	0.15	Railway Ave

	
1. Upper Tsolum R below ravine	2. Upper Tsolum above Hell Diver Cr
	
3.Hell Diver Creek through wetlands	4. Tsolum R below Hell Diver Cr
	
5. Constitution Cr at DBM 3700 crossing	6. Tsolum R below Constitution Cr

		
7. Tsolum R at Inland Island Hwy		8. Tsolum R above Headquarters Cr

Appendix 4: Tsolum River System Measured Mean Monthly and Annual Discharges at WSC gauge sites

	Mean Monthly & Annual Dischares														
		Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly
Tsolum R	average daily since 1977	258	19.5	19.1	14.8	10.4	6.3	3.7	1.5	1	1.7	7.4	18.6	20.2	10.3
	average daily 1985-2004	**258**	**21.5**	**17**	**14.4**	**10.5**	**6.1**	**3.9**	**1.4**	**0.9**	**1.2**	**6.4**	**17.4**	**20.6**	**10.1**
	average daily 1995-2004	258	23.8	17.6	15.7	10.8	6.8	4	1.5	0.8	1.7	9.3	20.4	22.4	11.3
Dove Cr	**average daily 1985-2004**	**41.10**	**3.91**	**3.06**	**2.74**	**2.23**	**1.08**	**0.62**	**0.23**	**0.12**	**0.22**	**1.41**	**3.36**	**3.82**	**1.90**
Browns R	average daily since 1960	86.00	7.52	5.52	5.34	7.52	10.02	6.84	2.03	0.83	0.82	5.88	8.01	7.14	5.62
	average daily 1985-2004	**86.00**	**7.16**	**5.10**	**5.89**	**8.21**	**10.03**	**5.64**	**1.87**	**0.91**	**0.77**	**4.65**	**7.95**	**6.19**	**5.36**
	Unit flows (per km^2)														
Tsolum R	average daily since 1977		0.076	0.074	0.057	0.040	0.024	0.014	0.006	0.004	0.007	0.029	0.072	0.078	0.040
	average daily 1985-2004		**0.083**	**0.066**	**0.056**	**0.041**	**0.024**	**0.015**	**0.005**	**0.003**	**0.005**	**0.025**	**0.067**	**0.080**	**0.039**
	average daily 1995-2004		0.092	0.068	0.061	0.042	0.026	0.016	0.006	0.003	0.007	0.036	0.079	0.087	0.044
Dove Cr	**average daily 1985-2004**		**0.095**	**0.075**	**0.067**	**0.054**	**0.026**	**0.015**	**0.006**	**0.003**	**0.005**	**0.034**	**0.082**	**0.093**	**0.046**
Browns R	average daily since 1960		0.087	0.064	0.062	0.087	0.117	0.080	0.024	0.010	0.010	0.068	0.093	0.083	0.065
	average daily 1985-2004		**0.083**	**0.059**	**0.069**	**0.095**	**0.117**	**0.066**	**0.022**	**0.011**	**0.009**	**0.054**	**0.092**	**0.072**	**0.062**
	Monthly volumes (hectare*meters)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly
Tsolum	**average daily 1985-2004**		5759	4113	3857	2722	1634	1011	375	241	311	1714	4510	5518	31763
Dove Cr	**average daily 1985-2004**		1048	741	734	578	289	160	63	31	57	378	900	1023	6003
Browns	**average daily 1985-2004**		1917	1234	1578	2128	2686	1462	500	245	199	1246	2130	1658	16981
	Monthly volume/km^2 (ha.m)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly
Tsolum	**average daily 1985-2004**	258	22.3	15.9	14.9	10.5	6.3	3.9	1.5	0.9	1.2	6.6	17.5	21.4	123.1
Dove Cr	**average daily 1985-2004**	41.1	25.5	18.0	17.8	14.1	7.0	3.9	1.5	0.8	1.4	9.2	21.9	24.9	146.0
Browns	**average daily 1985-2004**	86	22.3	14.4	18.3	24.7	31.2	17.0	5.8	2.8	2.3	14.5	24.8	19.3	197.5

Gooding Hydrology
dgooding@saltspring.com

Appendix 5: Monthly, yearly, and wet season inflows to potential storage locations

														89%	83%	
unit input for monthly inflow below			*22.3*	*14.4*	*14.9*	*10.5*	*6.3*	*3.9*	*1.5*	*0.8*	*1.2*	*6.6*	*17.5*	*20.7*	107	100.3	120.6
(hectare m)/km^2																
watershed	area (km^2)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Oct -Apr	Nov-Apr	yearly
WOLF LAKE	19.9		443.8	286.6	296.5	209.9	125.4	78.0	29.9	15.9	24.0	131.3	347.9	411.8	2128	1996	2401
HELL DIVER LAKE	6.26		139.6	90.1	93.3	66.0	39.4	24.5	9.4	5.0	7.5	41.3	109.4	129.6	669	628	755
LITTLE LOST LAKE	1.47		32.8	21.2	21.9	15.5	9.3	5.8	2.2	1.2	1.8	9.7	25.7	30.4	157	147	177
LOST LAKE incremental	0.87		19.4	12.5	13.0	9.2	5.5	3.4	1.3	0.7	1.0	5.7	15.2	18.0	93	87	105
LOST & LITTLE LOST LAKES	2.34		52.2	33.7	34.9	24.7	14.7	9.2	3.5	1.9	2.8	15.4	40.9	48.4	250	235	282
REGAN LAKE	7.47		166.6	107.6	111.3	78.8	47.1	29.3	11.2	6.0	9.0	49.3	130.6	154.6	799	749	901
BLUE GROUSE LAKE	3.56		79.4	51.3	53.0	37.6	22.4	13.9	5.3	2.8	4.3	23.5	62.2	73.7	381	357	430
BL GR - REGAN CONFL	14.7		327.8	211.7	219.0	155.1	92.6	57.6	22.1	11.8	17.7	97.0	257.0	304.2	1572	1475	1774

681 Rainbow Road, Saltspring Island, B.C. V8K 2M7 Phone: 250 538-1869 Fax:5338-1879

Appendix 6: Summary Table of Storage Options and Associated Works

Storage Location	Depth increase (m)	Dam Height (m)	Volume stored (ha-m)	Wetland Flooded (ha)	Forest Flooded (ha)	Est Dam Volume (cubic m)	Assoc. Works (cubic m)	Explanation and Comments
Wolf Lk	1	2	160	3	4			
	2	3	330	3	8		*65,000	*Constitution diversion channel excavation
	3	4	510	3	13		*40,000	*Constitution diversion channel excavation *See Wolf discussion for roadwork req'd as well
Hell Diver Lake	0.5	1.5	9	9	0	700		
	1	2	19	10	min	1,000		
Little Lost Lake	5	6	45	0.7	7	4,200	*	*plus 2 km road upgrade
	7	8	75	0.8	9	7,600	*	Average Oct thru April inflow 157 ha-m
Lost Lake	5	6	36	2.3	1.4	6,600	*	Average Oct thru April inflow 250 ha-m
	10	11	75	2.3	1.7	27,000	*	
	15	16	120	2.4	2.1	68,400	*	*plus 1 km road upgrade
Regan Lake	1	2	20	1.8	2	700	*	*plus 2 km road, ~1/3 will need to serve
	3	4	65	2	5	2,600	*	as dams along divide from 0 to 3 m high
Blue Grouse Lake	5	6	65	3.7	12	9,000	*	*1 km road upgrade
	10	11	175	4	16.5	25,000	*	*likely long auxiliary dams at divides
Bl Gr-Regan confl	15	16	90	min	20	*50,000		*Preliminary estimate
	20	21	200	1.5	25	*112,000		

Entries in blue based on topographic map study only.
Note: Volume of material in dam assumes 1.7:1 side slopes on dam, and a 5 m wide top.

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