HYDROLOGY, WATER USE AND CONSERVATION FLOWS FOR KOKANEE SALMON AND RAINBOW TROUT IN THE OKANAGAN LAKE BASIN, BC

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IMPORTANT

The present study has been conducted on the basis of available information and previous reports, limited by the available time and budget. Numerical estimates provided herein represent attempts to satisfy the requirements of the study on the basis of available information and professional judgement, but in many cases they are subject to uncertainty.

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EXECUTIVE SUMMARY

The purpose of this study was to express the habitat sensitivity of twenty-one tributaries to Okanagan Lake, through various indices that are calculated from natural flows, water use, land use and physiography in their watersheds. The study streams support spawning runs of either rainbow trout (*Oncorhynhcus mykiss*) or Kokanee salmon (*Oncorhynhcus nerka*).

Re-construction or estimation of the natural hydrologic regime was one of the most important tasks. The study also calculated potential licensed demands on surface waters, assessed potential effects of land use on hydrology, described fish periodicity, and provided preliminary conservation flows. Sensitivity indices calculated from the natural flows, water demands, and land use were used to rank the tributaries for meeting conservation flows, water withdrawals, low flows, peak flows, forest harvesting and urbanization. The most sensitive streams included those that were most affected by human activity and those that, because of their hydrologic regime, have the least ability to resist human impacts.

All the tributaries, except Prairie Valley Creek and Thompson Brook, have licences for irrigation, waterworks, domestic, or industrial extractions. In the large and mediums-sized watersheds, withdrawals are often supported by storage development and the net licensed demand on summer and winter low flows is theoretically small. The greatest demands on low flows seem to occur in small tributaries, particularly Naramata, Eneas, McDougall and Naswhito Creeks. Large demands, in excess of storage, also appear on tributaries near Vernon, such as B.X., Deep and Vernon Creeks and on Trepanier and Powers Creek near Peachland. Groundwater is extracted from many aquifers around Okanagan Lake. These extractions may reduce low flows in some tributaries but the actual effect on surface waters has not been studied.

A number of the tributaries have no stream gauging records or only occasional miscellaneous measurements. Continuous streamflow measurements to supplement existing programs, combined with measurements of storage, diversions and extractions, would assist in reconstructing natural hydrographs for small tributaries and better defining conservation flows.

Storage fills during the snowmelt freshet, potentially reducing the magnitude and duration of the mean annual flood in downstream reaches. The consequences may be less frequent movement of bed material, aggradation, fining of the bed material, and sedimentation of instream gravel. Unusually low peak flows, relative to mean annual flow, occur in Peachland, Kelowna, Vernon, B.X. and Deep Creeks. Trepanier, Lambly and Bellevue Creeks have the greatest mean annual floods (as a percentage of mean annual flow). Scour of bed material, frequent transport of bed material, and channel erosion are expected. Forest harvesting is thought to play a role in increasing peak flows in Lambly and Bellevue Creeks.

The lower reaches of several of the tributaries are aggrading. Naramata and particularly Mission Creek have had gravel removal as part of flood control and channel management. Detailed studies of the sources of the coarse material and potential source management programs have not been undertaken. Such programs would greatly assist management of these streams.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. INTRODUCTION

1.1 PURPOSE OF THE STUDY

An understanding of natural and regulated hydrology in the tributaries to Okanagan Lake is an important aspect of fish habitat management planning and our report describes both their natural regimes as well as the effect of human development on those regimes. Storage and extraction of surface water for agricultural, municipal or industrial purposes and the effects of urban development and forest harvesting on floods and low flows are the main hydrologic issues.

The main objective of the study is to express the sensitivity of Kokanee and Rainbow Trout streams through various indices that are calculated from natural flows, water use, land use and physiography in their watersheds. The indices are used to rank the streams and the most sensitive streams include those that are most affected by human activity and those that, because of their hydrologic regime, have the least ability to resist human impacts.

Re-construction or estimation of the natural hydrologic regime is a key aspect of the study. However, extensive development of water resources, inter-basin diversions, and extractions that constitute a large portion of the annual runoff mean that few streams have natural flows and that most Water Survey of Canada (WSC) gauging records near the mouths of these streams reflect only the regulated hydrologic regime. These factors, plus the arid climate and small annual flows, greatly increase the difficulty of developing accurate estimates of natural flow characteristics.

1.2 SCOPE OF THE STUDY

The Okanagan Lake Basin is the area that contributes to, or drains to, Okanagan Lake. The lake has a total of 46 named tributaries. Our study examines twenty-one of these tributaries that support spawning runs of either rainbow trout (*Oncorhynhcus mykiss*) or Kokanee salmon (*Oncorhynhcus nerka*) (Table 1).

The main task was calculating flow characteristics for the 21 tributaries to Okanagan Lake. The quality of information varied greatly from stream to stream; however, we tried to estimate flow characteristics in a consistent manner so that the study streams could be compared and ranked. The estimated flows are not necessarily the best estimate for any individual stream and should not be used for design of structures or evaluation of projects without further, detailed study of that particular stream.

Our analysis is based on information obtained from the Water Survey of Canada, the Ministry of Environment, Lands and Parks or the Municipalities around Okanagan Lake and discussions with staff of various provincial and federal government departments and agencies.

1.3 PREVIOUS STUDIES

The Ministry of Environment, Lands and Parks, through the Water Management Branch, has been very active in the Okanagan Lake Watershed. As part of the Canada-British Columbia Okanagan Basin Agreement, a number of hydrologic and other studies were carried out, culminating in the Comprehensive Framework Plan (OBA 1974). The plan provided specific flow and other recommendations to maintain fish habitat in the main tributaries to Okanagan Lake. Subsequently, The Okanagan Basin Implementation Agreement (OBIA) followed on from the Okanagan Basin Agreement.

Hydrology has always been a key issue in the Okanagan Watershed and the Water Management Branch has undertaken numerous regional and basin studies, primarily to predict runoff in ungauged watersheds or the flows available for storage or extraction. The earliest regional study was by Reksten (1973) who related 1971 and 1972 April to July unit runoffs to various physiographic parameters to predict natural flows. Letvak (1980a & b) later summarized a series of reports and provided equations for estimating natural annual runoff on the east and west sides of the Okanagan Valley. Detailed reconstruction of natural flow regimes seems to have focused on Duteau Creek, which is a tributary to Bessette Creek within the Shuswap watershed. Coulson (1971) first examined storage requirements on Duteau Creek; in 1973, he updated the study to include additional years of measurements and re-constructed the natural flow regime. Rood (1989) subsequently updated Coulson's estimate of storage requirements, re-constructed the natural hydrologic regime, and recommended modifications to reservoir operation to benefit fish in Duteau Creek.

Most recently, Shepherd and Ptolemy (1999) reviewed the history of water management and habitat issues in the main tributaries of the Okanagan Watershed and summarized studies of flow requirements for Kokanee and Rainbow Trout.

1.4 ACKNOWLEDGEMENTS

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2. OKANAGAN LAKE WATERSHED

Climate, in combination with physiography and geology, can be used to define broad regions of similar hydrologic behaviour. As is discussed in the following sections, the tributaries lie mostly within one physiographic region, mostly within one ecoregion (Table 2; also Figure 2) and within the Southern Interior hydrologic region (Coulson and Obedkoff 1998). The ecosections and physiographic regions correspond fairly well, and the following discussion is based on the physiographic regions.

2.1 PHYSIOGRAPHY AND ECOPROVINCE

The Okanagan Lake Watershed has an area of 6,090 km^2, a normal annual inflow to Okanagan Lake of 15.1 m^3/s (Coulson and Obedkoff 1998), and lies mostly within the Thompson Plateau physiographic region. The Penticton Creek watershed extends into the Okanagan Highland southeast of Okanagan Lake and Deep Creek extends into the Shuswap Highland, northeast of Okanagan Lake (Holland 1976; Matthews 1986; Table 2). Bedrock varies from the metamorphic rocks of the Monashee Formation east of Okanagan Lake, primarily consisting of gneiss and quartzite, to plutonic rock to the west. Andesite and trachite are exposed near Kelowna, Westbank and Summerland (Wittneben 1986). Roed (1995) provides a detailed discussion of the origin of Lake Okanagan and the geologic history near Kelowna.

The Thompson Plateau is a rolling upland of low relief, lying mostly between elevations of 1,200 and 1,500 m (Holland 1976). Peaks rise to just over 2,000 m at Tahaetkun Mountain on the west side of the Lake and at Buck Mountain on the east side, but most are lower, at about 1,800 m. The Okanagan and Shuswap Highlands are transitional to the Thompson Plateau and the boundaries between the Highlands and Plateau are arbitrary (Figure 2).

The Plateau is deeply incised by the Okanagan Valley, which is oriented north to south with Okanagan Lake occupying the main trench at an elevation of about 340 m. A secondary or parallel trench extends north from Vernon and is occupied by Kalamalka and Wood Lakes; on the east side, an old meltwater channel parallels Okanagan Lake from south of Peachland to Marron Valley (Nasmith 1962). The Okanagan Valley ranges from about 3 to 15 km wide.

Okanagan Lake is the largest lake in the watershed with a surface area of 370 km^2 and a length of about 110 km (Figure 1). Its mean depth is about 70 m and its maximum depth reaches 230 m (Fulton 1975). Kalamalka and Wood Lakes are the next largest lakes. Numerous small lakes occur throughout the watershed, nearly all of which are developed for storage for agriculture or municipal water supply.

The Okanagan watershed is narrow compared to its length and the large tributaries which extend to elevations of 1,500 m, or so, at the crest of the watershed, drop steeply through narrow valleys before they cross their fans and enter Okanagan Lake (Figure 1).

2.2 SURFICIAL GEOLOGY

Nasmith (1962) mapped surficial deposits associated with late glacial history in the Okanagan Valley; Fulton (1975) later mapped the Quaternary geology of the Vernon map sheet in detail (82 L/SW), which covers the northern half of the Okanagan Watershed. Much of the exposed material was deposited during the last glacial advance of the Pleistocene. Uplands are primarily covered by discontinuous moraine (tills), with a typical thickness of 3 m. The texture of the till matrix varies from sandy to clay-rich, depending on the local bedrock geology and surficial materials overridden by the ice. Tills are thicker, and more continuous, in midlands, reaching an average maximum thickness of 4.5 m (Fulton 1975). Tills are absent from steep slopes and are often buried by other deposits in valley bottoms (Fulton 1975).

Most surficial deposits at low elevations result from the stagnation and melting of the tongue of glacier ice in the Okanagan Valley after the uplands had become ice-free (Nasmith 1962). During deglaciation, water levels in Okanagan Lake dropped from a maximum of about 550 m to near present lake levels. Glaciolacustrine sediments deposited marginal to the ice and on the lake bottom are now exposed in cliffs along the valley bottom, from Penticton to Summerland, near Kelowna and Vernon, at the north end of Okanagan Lake and along the valley leading to Enderby (Nasmith 1962; Fulton 1975). Often, the glaciolacustrine deposits are covered by thin layers of other sediments below elevations of about 500 m.

Many of the tributaries to Okanagan Lake were meltwater channels during deglaciation of the uplands or while drainage was blocked by ice in the main valley. As a result, they are often deeply eroded and partly filled with glaciofluvial deposits. The lower reaches of Deep Creek flow along a major meltwater channel, as does Coldstream Creek (Fulton 1975). Equesis Creek Valley is filled with glaciofluvial deposits below about 800 m. Less detailed maps are available for tributaries in the south half of the watershed, but Peachland and Eneas Creeks were meltwater channels and Trout Creek, downstream of Faulder, flows through glaciofluvial deposits to its mouth. A prominent channel extends along Darke Creek, past Trout Creek to Marron Valley, which may divert groundwater from Shingle Creek to lower Trout Creek through the infill deposits (Nasmith 1962).

During deglaciation, when Okanagan Lake was much higher than at present, fans and deltas formed well above present levels. These fans were later incised and the eroded material transported to reconstruct fans at successively lower levels. Mission Creek exhibits a particularly large series of fan and delta deposits, though raised fans or kame terraces are prominent along the lower courses of most of the large tributaries (Fulton 1975). The size of recent fans constructed in Okanagan Lake provides some evidence of coarse sediment transport, most of which occurred just after deglaciation. Mission Creek has a particularly large fan. The combined fan of Equesis and Naswhito Creeks is also very large, as is that of Whiteman Creek. Shorts Creek fan is prominent, as is the recent fan of upper Vernon Creek into Wood Lake. McDougall Creek has a moderate-sized fan partly composed of debris flow deposits (Roed 1995); Powers and Trepanier Creeks, small ones. Penticton Creek has a large fan; Penticton sits on it.

2.3 REGIONAL CLIMATE

The Thompson Plateau lies in the rainshadow of the Coast and Cascade Mountains and the Okanagan Watershed has a semi-arid continental climate, characterized by hot, dry summers and cold winters. Average daily temperature ranges from about 8°C at Vernon at the north end of Okanagan Lake, to 10°C at Osoyoos, near the US border (Table 3). January is the coldest month with a normal mean temperature of –3.3°C at Kelowna, near the middle of Okanagan Lake. Temperatures drop to a minimum of about –25 to –30°C when arctic air intrudes into the valley (Wittneben 1986; Valentine *et al* 1978). The Kelowna climate station, at an elevation of 354 m, records normal average maximum July and August temperatures of 27.9 and 26.8°C. Extreme maximums reach 38.9 and 36.1°C at this low-elevation station (AES 1985).

Normal annual temperature declines with elevation, and is only 2.8°C at McCulloch at 1,280 m (Table 3). Average maximum temperatures in July and August (22.1 and 21.6 °C) at this station are also considerably lower than at Kelowna.

Normal precipitation at the Kelowna climate station, on the valley bottom, is 332 mm; 97 mm (29%) falls as snow. Other valley bottom stations (Vernon, Okanagan Centre, Peachland, Summerland, Penticton A, Osoyoos; see Table 3) record similar annual totals, though there appears to a trend to lower precipitation in the south compared to the north, leading to lower annual runoff (see Reksten 1973; Obedkoff 1988). Precipitation is distributed fairly evenly throughout the year, with a springtime minimum and summer and winter maxima.

May to September precipitation ranges from about 110 to 150 mm along the valley bottom. Totals are less than evapotranspiration and soil moisture deficits of around 200 to 400 mm are expected each year (Valentine *et al* 1978). Reksten (1973) notes that summer circulation is dominantly westerly and greater rainfall is expected on west-facing slopes than on east-facing ones. Recorded greatest daily precipitation is typically about 30 to 40 mm, with totals of over 60 mm at Kelowna (Table 3). These storms occur in the summer and fall.

Total precipitation and the portion falling as snow both increase with elevation. The McCulloch climate station, at an elevation of 1,250 m, has normal precipitation of 663 mm, or about double that at lake level. About 55% of the total falls as snow (Table 3). Elevation exerts considerable control over precipitation, as seen in the contours on the mean annual runoff maps of Coulson and Obedkoff (1998; Figure 4).

Maximum normal water equivalents in the snowpack, as measured by the Water Management Branch, increases with elevation, though other factors cause large variation in the maxima observed in various elevation bands (Figure 3). Silver Star Mountain snow course (2F10), at an elevation of 1,840 m, records the greatest normal water equivalent of about 730 mm. Melt at this elevation begins in late April and is mostly complete by June 15th. The McCulloch snow course (2F03), at an elevation of 1,280 m, has a much lower normal maximum water equivalent of 162 mm. Here, melt is complete by May 15th.

2.4 REGIONAL HYDROLOGY

The Okanagan Lake Watershed lies in the lower half of the Southern Interior hydrologic region (Region 12). Coulson and Obedkoff (1998) show that mean annual flow increases with elevation to the east and west from Okanagan Lake and is expected to vary from less than 100 mm to more than 200 mm, depending on the elevation and position of the watershed (Figure 4). Based on Figure 4, large tributaries would have annual runoffs of about 150 mm at their mouths, as averaged over their watersheds; the very largest tributaries from the east, such as Mission Creek, have substantially greater runoff.

Elevation seems to be the key factor affecting annual runoff. In the Equesis Creek watershed, annual runoff is estimated to be less than 50 mm at elevations below 1,200 mm. Runoff then increases rapidly to over 400 mm in the upper elevations in the watershed, as a result of both increased precipitation and greatly reduced evapotranspiration (Letvak 1994; see also Letvak 1980a & b). To a lesser extent, annual runoff also varies from north to south. Obedkoff (1998) sub-divided the Southern Interior hydrologic region 12 into subzones 12b (the southern half of the watershed to Kelowna) and 12e (the half extending north from Kelowna). (Upper Mission Creek and other creeks near Vernon extend into subzone 12c.) The subzone boundaries are based on physiography, geology, climate and analysis of flow records. Rood (1989) also identified a northern subzone, based on statistical analysis of Water Survey of Canada records.

Typically, slightly greater annual runoff occurs at a given median elevation in the north than the south; subzone 12c records greater annual runoff than 12e. Surprisingly, the southern subzone shows greater peak flows (10-year return period maximum instantaneous) for a given watershed area (Figure 5; see also Obedkoff 1998). Low flows (June to September and annual ten year return period 7-day low flows) are consistent over all three subzones with broad scatter around a general trend. They range from about 0.01 m^3/s (10 L/s) for a watershed area of 100 km^2, to about 1 m^3/s (1,000 L/s) for a watershed area of 1,000 km^2. Watersheds of less than 20 km^2 appear to usually have very small or negligible 7-day low flows.

In the Okanagan tributaries, about three-quarters of the annual runoff occurs from April through July, in response to melt of the winter snowpack (Rood 1989; Obedkoff 1978). The month with the greatest runoff varies with elevation in the watershed of the stream but usually is May in the larger tributaries to Okanagan Lake. It may be considerably earlier in the smaller, lower elevation tributaries. Mean monthly flows decrease after May, generally reaching a minimum in January or February.

Duteau Creek, which abuts the northern side of Mission Creek watershed but is part of the Shuswap Drainage, provides an example of re-constructed natural flows along the east side of Okanagan Lake (Figure 6; Rood 1989). This large stream, with lakes in its headwaters, has natural August and September flows that exceed 35% of the mean annual flow (expressed as a ratio not as portion of the annual flow volume). Natural winter flows are mostly above 20% of the mean annual flow, dropping slightly below this value in the coldest month, January. Natural flows in small, headwater tributaries show that average percentages of mean annual flow are 17% in January and over 20% in August and September at high elevations (see Appendix A).

The annual minimum flow typically occurs in the fall or winter during a cold, dry period (and often under an ice cover), although in some years the minimum flow occurs in the late summer. Natural summer and winter 7-day low flows at return periods of 10 years in the headwater tributaries are often not much different, though at more frequent return periods the summer flows are considerably larger (see Coulson and Obedkoff 1998; Appendix A).

Withdrawals, storage, and diversions have the potential to greatly alter the natural hydrograph in some of the study tributaries. For instance, near the mouth of Duteau Creek, re-filling of reservoirs in the upper watershed reduces monthly discharges during the snowmelt freshet by about half and is also expected to greatly reduce peak flows (Figure 6). In years with unusually large inflow volumes, the freshet peak may be delayed until July or August, when reservoirs are full and uncontrolled releases result (Rood 1989).

In Duteau Creek, late summer flows (September) are not much less than those that occur naturally but late fall and winter flows are well below natural flows (Figure 6). This occurs because of diversion for domestic use and waterworks and storage in reservoirs over the fall and winter, after the irrigation season, even though they generally fill and spill during the following freshet (Rood 1989). Note that storage in Duteau Creek is about equal to the total water licenses.

2.5 TEMPORAL VARIATION IN CLIMATE AND HYDROLOGY

Long-term records are available for several climate stations in the Okanagan Watershed, with Kelowna having records since about 1900 (Figure 7). This station shows increased temperatures in recent years and reduced snowfall, as a portion of total precipitation. The longest hydrologic record is the calculated annual inflows (not adjusted for extractions or evaporation) to Okanagan Lake (Figure 8).

Whitfield and Cannon (2000) describe recent climate changes in Canada. In the Southern Interior (Thompson Plateau) – comparing 1976-85 to 1986-95 climate records – temperature has increased in all months except February. Precipitation has increased during April and November and decreased in May, August and September, suggesting a shift in the annual precipitation pattern that leads to a longer, drier summer. Global warming, and its associated climate changes, is expected to result in reduced precipitation – leading to lower inflows to Okanagan Lake – coupled with more frequent extreme events, possibly resulting in unusually large floods

Historic records show considerable variation in the inflows to Okanagan Watershed (Figure 8). There is a broad pattern of relatively low inflows prior to 1945, followed by unusually high inflows from 1945 to 1954 and then again from 1975 to 1984. In recent years, the year-to-year variability of inflows seems to have increased (Figure 8).

Leith and Whitfield (1998) examined the consequences of recent climate change on the hydrographs of streams in south central BC. First, the onset of snowmelt freshet, as marked by the initial rise in streamflow, now occurs about 20 days earlier. The earlier snowmelt and the longer recession also result in lower flows in late summer. One other change is increased flow in early winter; warmer temperatures result in runoff from rainfall rather than snow accumulation.

Note that the earlier onset of the snowmelt freshet is also consistent with the effects of extensive forest harvesting (see Cheng 1980).

Leith and Whitfield (1998) do not include a formal analysis of snow survey stations. May 1st water-equivalents at Silver Star Mountain (1,840 m; Station 2F10) appear lower now than in the past, with particularly low values in the 1980s. Lower elevation snow courses (McCulloch, 2F03, 1,280 m; Trout Creek, 2F01, 1,430 m) show little trend in annual maximum water equivalents but show an earlier melt of the pack, with snow melted by May 1 at McCulloch for the past 15 years.

2.6 GROUNDWATER RESOURCES

Atwater *et al* (1994) describe the groundwater resources of the Okanagan Watershed. Groundwater reservoirs (or aquifers) recharge during snowmelt when vegetation is dormant and evapotranspiration is at a minimum, reaching maximum elevations in July (Westwold, Well No 45) or May (Oyama, Well No 172). They discharge during the summer, fall and winter when recharge is minimal, evapotranspiration consumes much of the rainfall, and demand is often greatest. Minimum elevations occur in April, prior to snowmelt recharge.

Atwater et al (1994) report 3,600 wells in the Okanagan Lake Watershed, with over half of these shallow dug wells of limited capacity and yield. Roughly 250 wells have yields in excess of 6 L/s and are used for irrigation, agriculture, and water supply. The higher yield wells are concentrated on the aquifers in deposits near Vernon, Kelowna, from Peachland to Summerland, and near Penticton (see Atwater *et al* 1994; their Figure 10.5). Total utilization is not known. However, observed groundwater levels at Westwold and Summerland appear to be declining, suggesting little potential for further development (Atwater *et al* 1994). Roed (1995) provides some details on the Rutland Aquifer which has been developed by the Rutland Waterworks District and notes that many water districts, rural developments, subdivisions, orchards and golf courses rely on groundwater wells entirely or to supplement surface water supplies.

It is likely that low flows in the lower reaches of tributaries that pass through thick glaciofluvial deposits are partly maintained by groundwater discharge from these aquifers. Raised deltas and terraces and Holocene channel and fan deposits, particularly those in the bottom of major valleys (Nasmith 1962) are thought to be important source of groundwater to streams but they are often also developed for irrigation and water supply.

Some streams may be effluent, losing instream flow to groundwater in their lower reaches. Shorts Creek is reported to often be dry in its lowest 0.25 km and significant losses to groundwater are also thought to occur in Trepanier and Lambly Creeks (Obedkoff 1990) and in Bellevue Creek. Mission Creek may also be groundwater effluent just above the head of its fan (Roed 1995). Trout Creek may gain water in its lowest reaches (Nasmith 1962), however, gauging records suggest that it may lose water. Deep Creek is thought to be groundwater influent, as is Kelowna Creek.

2.7 STREAM STABILITY

From the point of view of habitat management, a stable channel is one that maintains its physical characteristics: it is not eroding, incising (downcutting), widening, straightening, narrowing or aggrading. Stream channels become unstable for a variety of reasons, some of which are due to human activity. For instance, forest harvesting or urbanization may increase flood flows in streams that, in turn, may cause downcutting, widening and bank and valley wall erosion. Channels may also become unstable because of natural events, such as extreme rainstorms, or on-going channel adjustments related to slope or sediment load.

The stream response to these external factors is affected by channel slope, the size of bed material, the nature of material underlying the channel and channel pattern. In some instances there may be no immediate response, while in other instances it may be rapid and dramatic. Consequently, it is often difficult to ascertain a particular cause for an observed channel response or instability.

The typical tributary to Okanagan Lake starts in an upland area where thin deposits of glacial sediment or colluvium overly bedrock. Here, the channel is steep and often contained in an incised, narrow valley. Sediment is provided to the channel by snow avalanches, debris slides and flows from valley walls, and stream erosion of valley walls and channel banks. The lower reaches of the tributaries are often incised into thick accumulations of glaciofluvial or recent sediments before they flow onto their fan. Erosion of these deposits is often an important source of coarse sediment to the lower stream.

Table 4 summarizes reported channel pattern change (avulsion or channel shifts), bank and valley wall erosion, incision or downcutting, aggradation or channel filling, and bed material changes such as sedimentation and scour. Modifications including dikes, river training (including bank protection, diversions, revetments, spurs or bed control structures), channel encroachment (by land filling or dikes), gravel removal (dredging, bar scalping or deepening of the main channel), removal of riparian vegetation and removal of large organic debris

Table 4 is not comprehensive because some channel responses, such as slow downcutting, cannot be identified without detailed measurements. Also, it is based on interviews, reports and limited field visits and may be inaccurate, out-of-date or may reflect only a site-specific or localized situation.

2.8 FISH PERIODICITY

Periodicity is defined as that pattern or timing during a biological year when a given organism or life stage is active or present in the system under study. A fish periodicity chart (Table 5) of Mission Creek, the major tributary to Okanagan Lake, captures the weeks (where each "X" represents one week) and months during which each species' life history stage inhabits the stream. It recognizes that native fish species have adapted to both flow and stream temperature regimes over many years. The chart is also a convenient tool to super-impose the annual hydrograph and ecological needs of the stream channel to maintain habitat diversity and riparian habitats. The chart allows for critical review over the year of variable fish flow needs and human water demands.

The chart covers all aspects of the definition of fish habitat (Canada Fisheries Act; Section 34(1)). Fish habitats are defined as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes". Temperatures suited for growth largely dictate rearing periods. In this application, we have assumed that the growth season is represented by the days in which the mean daily stream temperature exceeds 7°C. The onset of rainbow trout spawner migration and reproduction is also linked to temperature, as well as threshold flows and other cues (turbidity). Empirical results of many fish studies from the Okanagan Basin are summarized here.

The intent of the fish periodicity chart is to use local fish knowledge and annotations to rationalize what discharge or "risk averse conservation flows" are appropriate for that critical time. It is common in flow setting procedures to default to the highest flow need for a particular period (Estes 1996) when there are several different flow needs due to over-lapping fish or ecological events. Failure to met certain conservation flows at one time of year has the affect of minimizing the benefit of better flows experienced for the rest of the water year (bottleneck).

These phenomena of habitat bottlenecks are important but often poorly understood (Weins 1977). The basic premise of the bottleneck is that populations of aquatic organisms are related to the availability of habitat *through time*. These flow-related habitat bottlenecks typically occur 1 to 3 or more years prior to maturation, when their effects are detectable in the adult population (Nehring and Anderson 1993; Bovee et. 1994). In addition, Bovee et al. (1994) found that:

1. There may be several consecutive and independent habitat events that can affect adult populations (such as spawner passage flows, spawning habitat, fry rearing habitat, parr rearing habitat, temperature regime, and adult feeding habitat);

2. Limiting events frequently occur over variable time scales;

3. Habitat may be limited by low or high flow events and by the rate of change of flow events with respect to habitat thresholds;

4. The smallest amount of habitat available during the year may not necessarily be the limiting event (such as over-wintering when fish are inactive); and

5. Habitat types not directly utilized by the target fish species (such as riffle-dwelling insects as it affects food supply for fish) may be more important than the habitat used directly by the species.

The periodicity chart includes, for each fish species:

- Adult migration or passage,
- Spawning (start, peak, end),

- Incubation,
- Emergence (from the gravel),
- Rearing,
- Over-wintering, and
- Juvenile migrant (smolt passage) movements to the lake.

The chart also includes ecological needs such as:

- Channel maintenance flows for channel geometry,
- Flushing flows for sediment removal,
- Wetland and off-channel wetted linkage, and
- Persistent wetting of riffle habitats for benthic invertebrate survival, high drift rates and fish food production.

3. HYDROLOGY

3.1 INTRODUCTION

The basic goal of the hydrologic analysis of the tributaries to Okanagan Lake is to predict the natural flow characteristics near their mouths. **Natural flows** -- those that would occur in the absence of developments that regulate or extract flows -- are required for the sensitivity indices so that licensed extractions can be expressed as a percentage of the total available flow and they are also utilized for estimating conservation flows.

The study tributaries have a broad range of watershed areas and we have classified them as large, medium and small. The three large tributaries are Trout, Mission and Vernon Creeks, each with a watershed area exceeding 700 km^2. The seven small tributaries have watersheds areas that are less than 100 km^2; the eleven medium sized tributaries have watershed areas between 100 and 300 km^2 (Table 7).

3.2 FLOW CHARACTERISTICS

3.2.1 DEFINITIONS

Table 6 defines the typical flow characteristics of the tributaries to Okanagan Lake. Significant characteristics include **"mean annual flows"** which expresses the total volume of water yielded from the watershed. **"Mean annual floods"** are also important. When combined with channel slope, they provide an indication of the potential for bed sediment transport, flushing of fines, scour of gravel in the stream during incubation or for channel erosion and enlargement. Peak flows at greater return periods are used for design of instream structures. **"Mean monthly flows"** for August and September express the average flow of water available during the driest portion of the summer rearing season when the peak removals for irrigation occur. Low flows in these months reduce rearing habitat, strand juveniles or fish food (insects) and are associated with high temperatures that reduce habitat quality. Mean monthly flow in January express the average flow of water available during the driest portion of the winter. A low flow in this month may affect incubating eggs by freezing de-watered or exposed redds. **"Seasonal 7 day low flows"** for the summer express the minimum flows during the summer rearing season and are used for fish habitat evaluations, calculating water allocations and water quality prescriptions.

3.2.2 REFERENCE POINT FOR FLOW CHARACTERISTICS

All flow characteristics, as well as water licence summaries, were prepared for the mouth of each stream as this was thought to be a representative and easily identified point. Flows at the mouth are usually representative of the lowest reach of the tributary stream. If a major tributary enters near the mouth the calculated flow characteristics may only represent a limited reach of the lower stream, downstream of its entrance.

3.2.3 Period of Record

In much of British Columbia, there is a consistent pattern of declining annual flows in the late 1940's and 1950's, above average annual flows in the 1960's and 1970's (Barrett 1979) followed by below average annual flows during the 1980's. Consequently, it is important when comparing records at different stations to limit or adjust flow data to a common period, if practical, so that variation between gauges reflects the character of the particular watershed rather than differences in the period of record.

Coulson and Obedkoff (1998) adopted the period of 1961 to 1995 for their inventory of natural streamflow in British Columbia and we have used this same standard period for this report. As very few stream gauges have continuous records over this period, it is necessary to adjust measured flows to this common period. We have used the long-term record of inflows to Okanagan Lake (see Figure 8) to adjust average flows measured over the period of gauge operation to the standard period, as described in Appendix A.

3.3 Flow Records in the Okanagan Watershed

The Water Survey of Canada is the prime agency collecting and reporting flow data in British Columbia. Gauging stations are described in *Surface Water Data Reference Index: Canada 1991*, or on *HYDAT Version 98: Surface Water and Sediment Data*, both published by Environment Canada.

3.3.1 The Water Survey of Canada

Active and inactive Water Survey of Canada (WSC) stream gauges on the main channels of the tributaries to Okanagan Lake are listed in Table 1 (see also Figure 2). The earliest continuous (year-round) gauges were installed in the early 1960s. Fifteen streams have gauging stations near their mouths that operated for five years or more; three stations continue to operate (Table 1). Many of these streams also have continuous, seasonal or miscellaneous records at other sites in their watersheds. The six smallest tributaries, with watershed areas less than 100 km^2, have no gauging records at all or only a few miscellaneous or seasonal years of record.

Nearly all of the gauging stations near the mouths of the tributaries measure regulated flow as upstream storage, diversion, or water extractions affect their records. One tributary has a gauging station near its mouth that records natural flows (Bellevue Creeks). Other tributaries have stations well above their mouths that record natural flows (e.g., Whiteman, or Deep Creeks; see Table 1), often well above storage reservoirs or diversion points. Most of the gauges with long-term records of natural flows in the Okanagan Lake watershed are at high elevations around its rim (see Coulson and Obedkoff 1998; Appendix A).

There are also gauging stations on other streams that lie within the Okanagan Lake watershed, or in nearby, similar areas. Where these stations provide useful information they are used in regional analyses of natural flow characteristics (See Appendix A).

3.3.2 Other Sources of Hydrometric Data

The Water Management Branch (WMB) of the Ministry of Environment, Lands and Parks operates some gauging stations whose data are reported by the Water Survey of Canada and they also operate a few stations that are only summarized in their reports (see Letvak 1980a and 1980b). The WMB also collects miscellaneous measurements to establish flows for approving licensed extractions, and carries out occasional (regional) data collection programs during droughts. Drought measurement programs (Richards 1977;Nyhof 1985; Nyhof 1987) include many small tributaries to Okanagan Lake. However, Deep Creek is the only study tributary with published observations in its lower reaches. As well, there are other miscellaneous measurements of the streams held by the Water Management Branch in Penticton.

A recent program of stream gauging on twelve of the tributaries to Okanagan Lake provides miscellaneous flows from the summer of 1999 and 2000 (Kirk 2000; Cassidy 2001). These flows have been examined to confirm our estimates of natural flows and to provide estimates of natural flows on Thompson Brook.

3.4 The Natural Hydrologic Regime

3.4.1 Approach to Estimating Flows

The flow characteristics calculated from gauging station records can be adjusted to represent the natural regime in the stream by adding potential water extractions, as calculated from summaries of water licences, to the flow recorded at the gauge. We have previously referred to these adjusted flows as **naturalized flows** to distinguish them from measurements of the natural regime (**nhc** and Hamilton 1994).

This approach provides a reasonable estimate of the natural hydrograph where there is little developed storage, where total storage is small in comparison to demands, or where licensed demand is low in comparison to natural flows. In these circumstances, naturalized flows are assumed to slightly over-estimate natural flows, because of differences between actual and licensed water use, flow enhancement by releases from small storage projects, and return flows from irrigation diversions.

The above conditions are not met in many of the Okanagan tributaries where inter-basin diversions, large storage volumes and high demand for water often prevent adequate estimation of the natural hydrograph by adjusting recorded regulated flows with licensed demands. However, it is usually possible to estimate mean annual flows by naturalizing records when unrecorded inter-basin diversions are not a factor, as carry-over or year-to-year storage seems to be insignificant in all of the tributaries. In several of the watersheds, with small storage volumes, it is also possible to naturalize monthly flows and seasonal 7-day low flows at gauges near their mouths, by this procedure (see Appendix A).

Regional hydrologic analysis seems to be the best approach to predict natural flow regimes at the mouths of some of the tributaries, particularly those with large storage quantities or inter-basin diversions and those that lack gauging records. The following sections and Appendix A provides further details on the estimation procedures.

3.5.2 STORAGE DEVELOPMENT AND NATURAL FLOW RECONSTRUCTION

Many of the Okanagan Lake tributaries have considerable licensed storage development, more than 30% of the mean annual flow in watersheds such as Kelowna, Penticton and Vernon Creeks (Table 10). In most instances, records of outflows, reservoir levels and storage-elevation curves are not available from the Water Survey of Canada or the Water Management Branch and inflows and natural outflows cannot be re-constructed. In a few watersheds, such as Duteau Creek, which is part of the Shuswap Watershed, detailed observations of the operating regime are available and have been used to re-calculate long-term natural monthly flows (Rood 1989). The natural hydrograph for Duteau Creek is particularly important, as it is the only known examples of natural flow characteristics calculated for the mouth of a medium-sized stream on the east side of Okanagan Lake.

3.5.3 MEAN ANNUAL FLOW

As described in Appendix A, mean annual flows in the study tributaries can be estimated from four procedures or sources:

- Regression equations prepared by Letvak (1980a & b)
- Previous reports and studies
- Subregional curves prepared by Obedkoff (1998)
- Naturalization of gauging records near the stream mouths

Appendix A summarizes the estimates from the above four procedures. These estimates vary considerably for individual tributaries and often the natural flows estimated by the regional analyses are substantially less than the recorded regulated flows. Typically, we have adopted a compromise between the naturalized flow records for those tributaries with gauges near their mouths and the regional estimates; for ungauged streams we have usually adopted the runoff estimates derived from the procedure by Obedkoff (1998). Eneas Creek was adjusted upwards as the regional estimate seemed to be inconsistent with the limited flow records on this stream.

3.5.4 MEAN ANNUAL FLOOD

Obedkoff (1998) provides envelope curves for natural unit 10-year annual maximum instantaneous flows at the long-term natural gauges in subregions 12b, 12c and 12e. The envelope curves have a constant slope, with unit floods decreasing with increasing watershed area, and they plot well above most of the observed data points. The individual unit floods show broad scatter. Obedkoff's curves, when adjusted to predict 2-year annual maxima, seem to over-predict floods at the mouths of the tributaries by a factor of about two.

We also prepared a regression between mean annual (instantaneous) floods for the WSC gauges with natural flows and watershed area (Appendix A). This equation also over-predicted the mean annual flood at the mouth of the tributary watersheds and was particularly unsatisfactory when extrapolated to large or small watersheds.

Mean annual floods were estimated from gauging records in preference to the equations, where they were available. However, for many streams the observed flows are affected by storage or diversion and, consequently, quoted mean annual floods under-estimate natural ones by some unknown amount.

3.5.5 Summer and Winter Monthly Flows

The water year was divided into two seasons: summer (May 1 to October 31) and winter (November 1 to April 30). This division included all irrigation within one season and separated low flows into two distinct seasons. Natural flows were predicted for August, September and January as these months typically have the lowest flows during the summer and winter seasons.

Where practical, natural mean monthly flows were predicted by naturalizing WSC gauging records. Mean monthly flows for the remaining tributaries were predicted from regional analysis. Unfortunately, unit mean monthly flows, expressed as a percentage of mean annual flow, were not correlated with watershed area or median elevation at WSC gauges with natural flows (Appendix A). Instead, natural monthly flows were predicted from percentages of mean annual flow observed for Duteau Creek or from the average percentages of mean annual flow reported in Table A2. Coefficients of variation were typically about ±30% (Table A2; Rood 1989).

Actual summer (August and September) and winter (January) mean monthly flows were calculated for tributaries with gauges near their mouths and more than five years of record. These flows were adjusted to the standard 1960 to 1995 period as described in Section 3.2.3.

3.5.6 Summer and Winter 7-Day Low Flows

Natural summer and winter 7 day low flows at a five-year return period were predicted for the mouths of Peachland, Trepanier, Powers, Lambly, Vernon, Kelowna and Mission Creeks by Obedkoff (1990). As is discussed in Appendix A, we have adjusted his predictions to a 2-year return period and adopted them, except for those from Peachland and Lambly Creeks. Significant storage and two diversions in Lambly Creek suggest that naturalization may not be satisfactory. Where practical, 7 day low flows were estimated by naturalizing WSC gauging records. Otherwise, 7 day low flows were estimated as a percentage of mean annual flow. Appendix A provides details.

Obedkoff (1990) also compared the natural 5-year 7 day low flows to the observed ones. The largest reductions occurred in Peachland, Trepanier, and Mission Creeks. Observed flows were only slightly less than predicted natural flows in the other four creeks.

3.7 Conservation Flows

The method considered most relevant for the preliminary quantification of instream fish flow needs and scoping of flow issues in water use planning is the Tennant Approach (Tennant 1976), as Annear and Conder (1984) found it to be the least biased of all the methods in common use. Conservation flow regimes for the salmonid-bearing tributaries of Okanagan Lake therefore were estimated using a Modified Tennant Approach as outlined by Estes (1996), which sets monthly or shorter period (such as passage times) minimum flow standards based on the highest flow required to meet species-specific life history demands. For Okanagan streams, conservation flows (as a percentage of mean annual flow) were set using a meta-analysis of a provincial database (unpublished data of R. Ptolemy), in combination with local information where available, as follows.

	Conservation Flow (as % of Natural Mean Annual Flow)			
Month	Kokanee	Rainbow	Both Spp	Nature of Life-History Demands
Jan	20%	20%	20%	Egg Incubation (KO) / Juvenile Over-Wintering (RB)
Feb	20%	20%	20%	Egg Incubation (KO) / Juvenile Over-Wintering (RB)
Mar	20%	20%	20%	Egg Incubation (KO) / Juvenile Over-Wintering (RB)
Apr	20%	46%	100%	Incubation & Emergence (KO) / Adult & Parr Migration (RB)
May[a]	>50%	100%	200%	Emergence (KO) / Spawning & Adult Migration (RB) / Flushing[a]
Jun	0%	100%	100%	Spawning, Adult Emigration & Egg Incubation (RB)
Jul	0%	40%	40%	Spawning, Adult Emigration & Egg Incubation (RB)
Aug	0%	30%	30%	Juvenile Rearing / Temperature Moderation (RB)
Sep	20%	25%	25%	Adult Migration & Spawning (KO) / Juvenile Rearing (RB)
Oct	20%	20%	20%	Adult Migration & Spawning (KO) / Juvenile Rearing (RB)
Nov	20%	20%	20%	Egg Incubation (KO) / Juvenile Over-Wintering (RB)
Dec	20%	20%	20%	Egg Incubation (KO) / Juvenile Over-Wintering (RB)

NOTES

[a] For channel maintenance over the longer term, a maximum instantaneous flow of 500% of MAD with a 1:2 year frequency is recommended

It should be noted that the above standards could vary, depending on the actual timing of annual peak flows and variations in water temperature regimes, as well as stream size and configuration (for example, less water would be required for incubation if the spawning area was located in an incised single channel than if it were in a shallower braided area).

3.8 SUMMARY OF GAUGING RECORDS

The flows recorded at gauging stations near the mouths of the tributaries are of interest for more than establishing natural flow characteristics at their mouths. For some streams, gauging records permitted calculation of existing (regulated) flow characteristics such as mean annual hydrographs, mean August, September and January monthly flows, monthly distributions of annual 7 day low flows, and 7 day low flow frequency curves. These flow characteristics are not naturalized because of the difficulty of adjusting daily flows for each year.

Appendix B includes Summary Sheets for each stream. These sheets provide mean annual hydrographs calculated from all available complete, continuous years of record at the gauge. The Summary Sheets also provide details on licensed extractions, naturalized flows and rankings for the sensitivity analysis.

Details are also provided on 7 day low flows for some stream with gauges near their mouths. The distribution, by month, of the annual 7 day low flows, is based on all complete years of record at the gauge. 7 day low flow frequency curves for these stations are also included, where there are a sufficient number of observations.

4. LAND USE

4.1 OVERVIEW

The natural hydrologic regimes of the tributaries to Okanagan Lake have been altered, to varying extents, by land use. Urbanization, agriculture and forest harvesting all have the potential to alter the hydrologic regime. Agriculture affects the hydrologic regime by extracting surface and ground water for stock watering, domestic use and irrigation and it may also causes a minor increase in flood discharge through conversion of lands. Urbanization primarily affects the hydrologic regime through extractions for waterworks. However, urbanization also potentially has a significant effect on flood discharges in some of the smaller tributaries.

The removal of timber during forest harvesting (or agricultural land clearing) alters transpiration and the distribution of snow and may often increase rates of melt. These changes in the watershed, coupled with road construction and soil modifications tend to increase water yield (mean annual flow), mean annual floods and summer base flows.

There are also secondary effects on stream channels associated with increased flood flows. In suitable materials, channels often enlarge through bank erosion and channel incision. These processes, along with sediment released from harvesting activities, may greatly increase the quantity of sediment transported through the stream.

4.2 FOREST HARVESTING

Haul and skidder road construction compact the surface and increases runoff from the road surface and increases the rapidity of runoff. Ditching along roads concentrates water, generally into fewer channels, and intercepts subsurface flow, increasing the speed of flow to drainage channels. The removal of trees reduces or eliminates transpiration, in the short-term. Tree removal also increases air movement and changes soil temperature, which tend to increase evaporation from the soil surface, but the overall effect is to reduce evapotranspiration from the soil. Harvesting also affects the distribution of snow and the timing of its melt.

4.2.1 STREAMFLOW QUANTITIES

Well-designed experiments generally show increased water yield as a response to forest removal, and the increase is generally proportional to the amount of canopy removed (Bosch and Hewlett 1982). The increased flow of water results from increased storage of water in the soil as the result of reduced transpiration following the removal of forest cover. Increases are observed during the summer low flow season and also during the wet, or high flow season, particularly early in the season when soil storage differences are greatest between the forest and clearcut.

In snowmelt-dominated watersheds, clearcut-harvesting also produces increases in water yield. In Camp Creek near Penticton, logging following Pine Beetle infestation increased both annual and March to November monthly water yields, with the greatest increases recorded in the months of August and September (Cheng 1990). There was no consistent evidence of increased streamflow in the winter months. The Ministry of Forests (Kamloops) plans to re-visit and update the original study by Cheng on Camp Creek.

The Kamloops Forest Region is conducting snowpack and stream flow studies in Penticton Creek Watershed and also near Kamloops (Winkler 1999). In Penticton Creek, Winkler found that snowpack accumulations were 25% greater in clearcut areas than in a mature Englemann Spruce-Subalpine Fir forest and that spring snowmelt was 67% more rapid in the clearcut. A juvenile forest stand behaved similar to the clearcut, showing no hydrologic recovery. A mature Lodgepole Pine forest behaved in an intermediate manner between the mature forest and clearcut, indicating that changed forest composition can affect hydrologic recovery. To date, 10% of the watershed of Upper Penticton Creek has been harvested and little change in the stream hydrograph has been observed (Winkler; personal communication).

4.2.2 Flood Flows

Many studies have demonstrated increased storm volumes and peak flows following forest removal, though there are few results appropriate to the parts of British Columbia where snowmelt is the dominant mechanism for flood generation. Cheng (1990) found increased, and earlier, peak flows in Camp Creek after logging of 30% of the basin area. His finding of a 20% greater, and two weeks earlier, flood peak are roughly comparable with studies in other snowmelt-dominated systems. For instance, King (1989) examined streamflow responses in northern Idaho following harvesting and found increases of 15 to 35% in maximum instantaneous discharges.

4.3 Assessment of Hydrologic Impacts

4.3.1 Harvested Areas in the Tributaries

GIS databases maintained by the Ministry of Forests were used to estimate harvested areas in the watershed of each tributary. Harvested areas in each watershed are described on Table 7 as:

- Prior to 1980
- 1980 to 1989
- 1990 to 1999
- 2000; and
- Unknown, which includes those cutblocks with no date. They are assumed to be mostly older blocks, cut well before 1980. Note that this constitutes the largest category in some of the watershed.

The total harvested area for each age category is quoted as a percentage of total watershed area on Table 7. The totals are not corrected for partial harvest in cutblocks nor is the large burnt area in Penticton Creek included in the totals.

It is difficult to assess impacts on harvesting on peak flows in the lower reaches of the large tributaries based on harvested areas expressed as percentage of the total watershed, particularly when the date of cut of large areas is not known. However, several watersheds have a total cut, expressed as percentage of their total watershed area, over the past twenty years that suggests modifications to the hydrograph may have recently occurred. These watersheds are Lambly, Naswhito, Naramata, Bellevue, and Mission Creeks (Table 7). Trout, Powers and Whiteman Creeks have a smaller recent cut, but some potential for increased peak flows from this harvesting.

Harvesting may also have increased flood flows in some watersheds more than 20 years ago. Hydrologic recovery may now have reduced peak flows; however, stream channels may not yet have recovered from the increased peak flows.

4.3.2 Interior Watershed Assessment Procedure

Watershed Assessments, through the Interior Watershed Assessment Procedure (IWAP), have been completed for some, but not all, of the tributaries to Okanagan Lake. These studies indicate existing high peak flow hazards at the mouth of Lambly Creek and moderate hazards at the mouth of Powers and Naramata Creeks (Dobson Engineering Ltd 1998a, 1998b, 1999). Trout, Mission and Penticton Creeks were reported to have low peak flow hazards at their mouths although some of their upper sub-basins recorded moderate or high hazards. Low peak flow hazards are reported for Naswhito and Equesis Creeks (B. Robertson, personal communication). Storage development and operation mitigates the effects of forest harvesting on peak flows in some watersheds.

4.4 Urban Land Use

Urbanization alters the hydrologic regime in several ways. Development of waterworks, either from groundwater or surface water, may reduce mean annual flows, mean annual floods and seasonal 7 day low flows. However, the main hydrologic impact of development often results from the creation of impervious surfaces that are directly connected to watercourses. These surfaces change the runoff processes -- rapid flow over impervious surfaces and through pipes is substituted for less rapid interflow (lateral flow through soils) -- speeding the delivery of water to streams and increasing both the volume of runoff and the maximum discharges reached during a rainstorm.

There are secondary effects associated with the increased flows. Stream channels often enlarge through bank erosion and incision or downcutting may also occur. These processes, along with sediment released from construction activities, often increase the quantity of sediment transported through the stream.

In the Okanagan Lake tributaries, floods are primarily generated by snowmelt in the upper, high elevation portion of the watersheds. Urban development, which is concentrated at low elevations along Okanagan Lake only has the potential to alter peak flows in small tributaries and is thought to have little or no effect on peak flows in the main channel of the larger streams.

4.5 MEASUREMENT OF IMPERVIOUS AREA

The effective impervious area in a drainage basin provides a quantitative measure of the potential alteration of the hydrologic regime imposed by urbanization. It is a measure of the total area where water does not infiltrate into the soil that is connected directly to the drainage network. The ineffective impervious area includes those impervious areas that drain to pervious terrain where stormwater infiltrates -- an example is a roof whose gutters discharge to a lawn rather than a stormwater drainage system.

Alley and Veenhuis (1983) and Dinicola (1990) describe how they estimated EIA from land use in Denver and King County, Washington. Their approach was followed to estimate EIA for the Okanagan Lake tributaries. First, 1:50,000 maps were used to identify those salmon streams where impervious area may account for more than a few percent of the watershed. For these streams, the watershed area covered by low density, medium density and high density single family houses, multi-family developments and commercial, industrial, and transportation facilities was measured from Zoning Plans made available by the various municipalities. Once the total area of each different land use was measured then the total impervious area within each type was estimated from typical percentages quoted in Alley and Veenhius (1983). The effective impervious area for each land use type was then estimated as a percentage of the total impervious area for each land use type and these were summed to calculate the EIA within each watershed (Table 8). The conversion to EIA assumes that not all impervious surfaces, particularly rooftops, are directly connected to the drainage network.

Table 8 shows significant EIA in Naramata and Kelowna Creek watersheds, primarily related to commercial and industrial development.

5. WATER LICENCES

The Water Rights Branch of the Ministry of Environment, Lands and Parks maintains a computerized database of water licences in British Columbia, which includes current licences plus outstanding applications. Summaries (by type) were produced for all the study streams.

5.1 CLASSIFICATION OF LICENCES

Table 9 reproduces part of the water licence classification system used by the Water Management Branch. Water licences are classified into consumptive and non-consumptive uses and further classified by the type of user. Computer-generated summaries, obtained from the Water Rights Branch, Victoria, utilize the main classification on Table 9, as well as providing more detail on the type of user, producing a total of 73 sub-categories (including non-consumptive uses).

5.1.1 CONSUMPTIVE LICENCES

The computer-generated classification provides more detail than is required so we have reported consumptive licensed extractions under the categories of Domestic, Waterworks, Irrigation and Industrial. Table 10 reports the sum of all licences, of each type, above the mouth of each tributary to Okanagan Lake.

5.1.2 NON-CONSUMPTIVE LICENCES

Non-consumptive water use includes power generation, storage (nonpower and power) and conservation. Conservation licences are totalled and summarized on Table 10. Nearly all the storage licences are non-power licences.

Storage licences in each tributary are also listed on Table 10. They are separated into storage specifically designated for domestic, industrial or waterworks licenses, storage specifically designated for irrigation licenses and other nonpower storage.

Storage generally fills during the spring freshet, reducing freshet flows. Irrigation storage is then released for consumption during the irrigation season; releases for waterworks use may occur throughout the year. Storage accumulation often begins again at the end of the irrigation season, reducing fall and winter flows further downstream.

Licensed storage volumes are often closely matched to waterworks and irrigation licences, and the net reduction in low flows resulting from diversion for irrigation is theoretically close to zero and certainly much less than the total licensed irrigation diversion. This does not work in practice as the upstream storage facilities trap incoming flows during low flows as well as high flows -- reducing downstream flows in addition to extractions -- and leaky dams and evaporative and transmission losses reduce the storage quantity available to compensate for licensed extractions.

5.2 Licensed Versus Actual Water Use

O'Riordan (1972) estimated licensed withdrawals, actual withdrawals and consumptive use for the Okanagan Lake Watershed. Actual withdrawals were typically about 60% of licensed volumes and under-utilization of licensed volumes seems fairly typical, except possibly during the driest years (see Rood 1989).

5.2.1 Domestic, Waterworks and Industrial Licences

Domestic use is only partly consumptive. In summer, although a large portion of the domestic use is for watering of lawns and gardens, some of this water re-enters the stream as return flow. Waterworks are also only partly consumptive; but in organized areas, water may be diverted out of the basin and return flows may not end up in the same stream, producing a true loss to streamflow. Typically, waterworks are licensed for amounts well in excess of actual extractions. Because licence-holders for large waterworks projects pay a fee based on actual water use, rather than the licensed amount, records are available of the annual volumes of water extracted from streams. We have not obtained these records for the Okanagan Lake tributaries because they are beyond the scope of the project.

Land improvement licences are not included in Table 10 but they were summarized for each tributary watershed. They are used to provide water for ponds, which may then be used for landscaping or to raise fish. On older licences, removal rates were set from an evaporation of one-eighth inch per day (doubled to one-quarter inch for a factor of safety), multiplied by the pond surface area, and converted to gallons/day. On newer licences, the licensee is permitted to divert whatever quantity is required to maintain water levels in his pond. The Land Improvement licences are consumptive, as most water is lost to evaporation although some may enter groundwater and re-appear as return flow. Most withdrawals will be during hot, dry weather when evaporation is greatest and streamflow is least. Much smaller withdrawals are expected during winter or rainy, cold weather.

5.2.2 Irrigation Licences

A certain percentage of the water diverted for irrigation re-enters the stream as return flow. When flood irrigation (by ditches and flumes) was prevalent it was assumed that roughly 30% of the diverted volume returned to the stream. Sprinkler and drip/trickle irrigation are expected to produce considerably lower return flows and these are now the dominant methods of irrigating.

Water applied to the land on a particular day will cause return flow some days, weeks or months later. In the Okanagan, it is assumed that 12% of the annual return flow occurs in September and 9% in October; and that a small percentage (about 4% per month) occurs through the winter months (Reksten 1976). Return flow in August and September may reduce the impact of irrigation diversions in those months if the flow reappears in a reach that supports fish and is not re-diverted out-of-channel. Recent flow audits and fish habitat assessments suggests that return flows are not mitigating sufficiently for abstractions.

Actual irrigation demand can be estimated from the area of irrigated land and a calculated or estimated water duty, where the duty is the water used over the irrigation season expressed as a depth. The theoretical duty and the actual amount applied can be very different, as a result of farming practices and, as well, the duty varies with location and elevation and from year to year. Year-to-year variations are significant: for example, from 1975 to 1988, duty in the Vernon Irrigation District varied from 31 to 48 cm (Rood 1989), with the greatest amount applied during low flow, dry years. In dry years the actual extraction approached the licensed volume.

We generally prefer to use the water licence summaries to estimate irrigation demand. As discussed in the next section, the licenses provide a potential maximum demand on the streams and provide a comparable standard from stream to stream.

5.3 CALCULATION OF LICENSED DEMAND

The water licences summarized on Table 10 are expressed in various units, ranging from acre-feet for irrigation licences, to gallons/day for waterworks and domestic licences, to ft^3/s for conservation licences. Licensed amounts expressed as discharges were converted to litres per second (L/s) using appropriate factors: 1 L/s is equivalent (approximately) to 19,000 imperial gallons/day; 1 L/s is equivalent (approximately) to 0.035 ft^3/s.

Licensed storage volumes (ac-ft) were converted to cubic decameters (dam^3), where 1 dam^3 is equivalent to 0.81 ac-ft. One acre-foot is equivalent to 743.36 gallons/day over a one-year period.

In any time period, the total demand is calculated by adding the demand from waterworks, domestic and industrial licences, which are assumed to be constant throughout the year, to the irrigation demand (Table 10). Irrigation demand varies from month to month over the growing season. Reported use in Duteau Creek averaged 5% in April, 14% in May, 21% in June, 28% in July, 25% in August and 6% in September (Rood 1989). Water Management uses a distribution of 5% in April, 10% in May, 20% in June, 25% in July and August, and 15% in September. The main discrepancy lies in water utilization in September. We have adopted a compromise distribution as follows: April (5%), May (10%), June (25%), July (25%), August (25%) and September (10%). Monthly irrigation volumes (in dam^3) were converted to discharges (L/s) by multiplying by 10^6, and dividing by the number of seconds in the month.

The total demand is calculated by subtracting irrigation storage volumes from irrigation licenses and by subtracting waterworks, domestic or industrial storage volumes from the waterworks, domestic and industrial licenses. Other non-power storage is then used to reduce irrigation demand to zero; any remaining storage is applied to waterworks, domestic and industrial demands. These adjustments provide an estimate of the licensed withdrawals that do not have associated storage volumes, and therefore directly reduce streamflow. Flows are then distributed by month as described above.

The above procedure provides a reasonable estimate of extraction demand on streamflows. However, it does not correctly account for the role of interception losses and evaporation that occur as part of storage, and reduce downstream flows, nor the alteration to the hydrograph that results from storage and release. Consequently, the reduction in natural streamflows that occurs is almost certainly under-estimated by the above procedure. However, it does provide consistent estimates of demands such that one watershed or stream can be compared to another.

6. SENSITIVITY INDICES

6.1 OVERVIEW

The sensitivity indices used here are of two general types:

- Indices that express the level of human activity in the watersheds of the salmon. These include expressions of the proportion of the watersheds that have been developed and the degree of utilization of water for irrigation, industrial and waterworks; and
- Indices that express the state of the particular stream and its ability to resist further change. These indices compare actual flows to conservation flows or express peak flows and low flows as a ratio or percentage of the mean annual flow. Extreme values indicate stressed systems with a limited ability to withstand further hydrologic alteration.

The indices are expressed as percentages of mean annual flow (Table 11). The most sensitive streams were defined as those with the most extreme indices or those with indices that exceeded some critical value (Table 12). The rationale for selecting the most sensitive streams is discussed separately for each index in the following sections. The indices are summarized in the table on the following page.

6.2 ACTUAL FLOWS COMPARED TO CONSERVATION FLOWS

Indices 1 and 2 express actual flows measured at stream gauges, as adjusted to the 1960 to 1995 period, as a percentage of the estimated natural mean annual flow. As noted earlier, 15 of the study streams have gauging records near the mouth of sufficient length to estimate actual monthly flows. Table 11 indicates the gauging station used in calculating actual flows.

Recommended conservation flows in August and September are 30% and 25% of the natural mean annual flow. Those streams with lower percentages are listed on Table 12.

6.3 SUMMER AND WINTER WATER DEMAND

Indices 3 and 4 express potential demands in August and September calculated from water licences, as percentages of natural mean flows in these months. The indices measure the total portion of the natural summer flows potentially devoted to irrigation and other water uses.

Table 12 lists the five streams that have the greatest potential water utilization based on these three indices. Several of the other streams potentially have more than half of their natural summer flows devoted to satisfying licensed demand.

6.3 SUMMER AND WINTER 7 DAY LOW FLOWS

Indices 5 and 6 express the natural 7 day low flows as a percentage of mean flow and indicate the ability of the stream to accept water extractions. Low values of the index indicate streams where 7 day low flows are small as a result of losses to groundwater, evaporative losses, or steep recession curves during summer drought. The streams with the lowest values of these indices are listed on Table 12.

Index	*Definition*	*Interpretation*
1	Actual flows in August as a percentage of the natural mean annual flow	Compares observed flows to conservation flows for this month
2	As above for September	As above
3	Potential demand in August as a percentage of mean August flow	Expresses the typical portion of flow during the rearing season that may be used for water demand
4	As above for September	As above
5	Natural mean summer 7 day low flow as a percentage of mean annual flow	Expresses the ability of the system to resist water removals; low values indicate streams with low natural 7 day low flows
6	As above for winter 7 day lows	As above
7	Mean annual flood as a percentage of mean annual flow	Expresses the peakiness of the snowmelt freshet and the potential for scour and erosion or sedimentation
8	Recent logged area as a percentage of total basin area	Roughly expresses the equivalent clearcut area and indicates the extent of hydrograph changes from logging; values exceeding 15% indicate potential changes in peak flows
9	As above for total logged area	As above

6.5 PEAK FLOWS

Index 7 compares the mean annual flood to mean annual flow, expressing it as a percentage of the mean annual flow. As described in Section 3, the quoted mean annual floods are mostly those reported at stream gauges. Consequently, they are affected by storage and, to a much lesser extent, diversion. As described in Appendix A, peak flow estimates on ungauged streams are thought to be too high; consequently percentages have not been quoted for Prairie Valley, Eneas, McDougall, Naswhito and Naramata Creeks and Thompson Brook.

The index is used to identify those streams that have unusually low ratios of mean annual flood to mean annual flow and, as a result, may experience sedimentation of their stream bed gravel. It has also been used, where practical, to identify those streams with unusually high percentages, that are potentially subject to scour of bed material.

6.6 FOREST HARVESTING

Index 8 expresses the area of recent logging (less than 20 years old) as a percentage of total watershed area. The equivalent clearcut areas of the recently logged areas are not known but are less than the area recently harvested. Index 9 expresses the area of total logging as a percentage of watershed area.

Total basin area was used instead of forested area in the index, primarily because forested area is not known. We have selected an arbitrary value of 15% for Index 10 to indicate when recent harvest may have altered the stream hydrograph at the mouth. Harvest of such a portion of the watershed is assumed to represent harvest of more than 20 to 30% of the forest in the watershed.

6.7 URBANIZATION

Total impervious area, expressed as a percentage of watershed area, was used as an index of urbanization. It indicates the potential increase in peak flows that might result from urbanization, though the actual increase will depend on detention storage constructed to manage stormwater, soils and underlying materials and the physiography of the watershed.

As discussed earlier, urbanization has little or no effect on the hydrologic regime in the main streams of the tributaries to Okanagan Lake and an index is not included in Table 11. However, both Naramata and Kelowna Creeks record large areas of EIA that may result in reduced water quality, affecting habitat directly.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 NATURAL FLOWS

In tributaries to Okanagan Lake, about three-quarters of the annual flow occurs during the snowmelt freshet, between April 1st and July 31st. The annual flood also occurs during the snowmelt freshet. Monthly flows decline after the freshet, usually reaching a minimum in January or February. 7 day low flows typically occur in January and February, often under ice cover, though the annual minimum sometimes occurs in late summer.

Annual runoff increases with elevation and, to a lesser extent, it also increases from south to north. Medium and large-sized tributaries that extend from Okanagan Lake to the rim of the watershed at around 1,800 m typically have annual runoff of around 150 mm. Runoff is much greater from Mission Creek, which extends into the Shuswap Highlands (Subregion 12c) and much less for small, low-elevation watersheds, such as Eneas, Deep and Prairie Valley Creeks. Diversions in and out of watersheds and extreme variability from year-to-year make it difficult to predict natural mean annual flows.

Natural monthly flows in late summer appear to average more than 30% of natural mean annual flow in the large northern tributaries and about 20% of natural mean annual flow in the moderate-sized ones. Monthly flows during the coldest winter month – January – average just less than 20% of natural mean annual flow. The standard error around these estimates is thought to be about ±30%. Lack of natural gauging records and a lack of flow and reservoir level records to reconstruct natural hydrographs make it difficult to determine which tributaries have relatively high and which have relatively low late summer and winter flows.

It appears that natural seasonal low flows in Shorts, Lambly, Bellevue, and Trepanier Creeks, when expressed as a percentage of mean annual flow, are smaller than in most of the other tributaries. Loss of flow to groundwater in their lowest reaches is the most likely explanation for this behaviour; however, steep recession curves after the freshet from a lack of soil storage or other storage in the watershed may also cause low natural flows. Inaccuracies in calculating natural low flows in Lambly Creek may be one of the reasons it is included.

Kelowna and Deep Creeks have unusually high natural seasonal low flows, when expressed as a percentage of mean annual flow, as does Peachland Creek in the summer. These streams also have unusual annual hydrographs with a smaller than normal percentage of flow from April to July and low mean annual floods relative to their mean annual flow (Appendix B). These streams are thought to be groundwater influent, as Whiteman and Equesis Creeks may also be.

Lack of stream gauging data makes it difficult to assess natural seasonal low flows in the small tributaries; however, it is likely that some of these tributaries should be included in the above lists.

7.2 CONSERVATION FLOWS

A modified Tennant Approach, which sets monthly and daily minimum standards based on the highest flow required for species-specific life history demands was used to define preliminary conservation flows (Tennant 1976; Estes 1996; Ptolemy 1999). Monthly and daily flows, expressed as a percentage of natural mean annual flows, were based on an analysis of a large province-wide database including empirical observations, combined with local instream flow studies.

The conservation flows are 20% over the winter, from October through March; they then rise to 100% in April and 200% in May, dependent on natural timing of snowmelt. Conservation flows, as a percentage of natural mean annual flow, then decrease through July, August and September. A more refined analysis would use daily flows in both a "wet" and "dry" year. Since some life-history events occur over days to weeks, flows over these shorter time spans would determine the likelihood of success for passage or spawning better than a mean monthly value. This principle also holds true for "flushing" flows and seasonal wetland linkage.

Examples of daily flows for Mission Creek near East Kelowna (08NM116) and natural daily flows at Whiteman Creek above Bouleau Creek (08NM174) are displayed in Figure 9. Natural summer baseflows can be lower than 10% of mean annual flow for extended periods, as occurred in 1987. This means that full utilization of water licences can affect fish more in a dry year than in an average or a wet year. Kokanee passage and spawning and rainbow trout parr rearing success are particularly vulnerable, since, as a general rule, their flow needs in September are often only just met by natural flows.

The daily flow hydrographs also show more "spikiness" in Mission than Whiteman Creek. Flow changes resulting from operation of diversions can be damaging to fish survival (if flows fall below certain thresholds) and may be hidden by daily, weekly or monthly averaging.

7.3 WATER USE

All the tributaries, except Prairie Valley Creek and Thompson Brook, have water licenses for irrigation, waterworks, domestic, or industrial use. In many of the large and medium-sized watersheds, licenses for withdrawals are supported by storage development and the net licensed demand on summer and winter low flows is theoretically small. In fact, several of the tributaries have large licensed withdrawal volumes but no apparent demand on summer and winter low flows because of compensating storage. However, storage does not completely eliminate the effect of licensed withdrawals on natural flows in the lowest reaches. Interception and storage of water from the upper watershed after the irrigation season, evaporative losses, and transmission losses are thought to lead to a net reduction in flow even when withdrawals are supported by storage.

For those tributaries with gauges, actual August and September flows are much less than recommended conservation flows in Trout, Trepanier, Lambly, Shorts, Penticton and Bellevue Creeks. As noted earlier, Trepanier, Shorts and Bellevue Creeks appear to have naturally low flows at their gauges. In some streams, the effect of demand seems to be more severe on 7 day low flows than mean monthly flows. In Trout Creek, recorded short term low flows are only a few percent of natural mean annual flows, apparently as a result of operation of diversions (see Appendix B).

Small tributaries, particularly Naramata, Eneas, McDougall and Naswhito Creeks, seem to have the greatest demand on their low flows, with the maximum potential demands often many times the estimated natural low flows. Large demands, in excess of storage, also appear on tributaries near Vernon, such as B.X., Deep and Vernon Creeks and on Trepanier and Powers Creeks near Peachland.

In watersheds with storage volumes that are a large portion of mean annual flow, the annual flood in lower reaches is reduced, the total volume of water delivered to the lower stream reaches during the freshet is reduced, and in some years the annual peak is delayed. Potential consequences of reduced peak flows and overall lower freshet flows are less frequent movement of bed material, aggradation and fining of the bed material in low gradient reaches and sedimentation of instream gravel. Unusually low peak flows, relative to mean annual flow, are observed in Peachland, Kelowna, Vernon, B.X. and Deep Creeks. Storage reduces peak flows in all these watersheds, although Peachland, Kelowna and Deep Creeks may have naturally low peak flows.

Trepanier, Lambly and Bellevue Creeks have the greatest mean annual floods, expressed as a percentage of mean annual flow. Scour of bed material, frequent transport of bed material, and bed and bank erosion are expected in these streams. Forest harvesting is thought to play a role in increasing peak flows in Lambly and Bellevue Creeks.

We do not know future water demand for irrigation. However, most streams are fully recorded and no licenses are likely to be issued without supporting storage. Conversion of water demand from agriculture to waterworks has occurred and may continue as urban areas develop. Shifting demands on flow to the winter when natural flows are least is expected to create further conflicts between requirements for egg incubation and over-wintering habitat and water use.

Groundwater is extracted from aquifers at several sites around Okanagan Lake, primarily from glaciofluvial and fan deposits. It appears that many of these aquifers are nearly fully developed (Atwater *et al* 1994). These aquifers may also support low flows in the lowest reaches of some tributaries. Many water districts, rural developments, subdivisions, orchards and golf courses rely on groundwater wells entirely or to supplement surface water supplies. The effect of extractions on low flows is not known.

7.4 LAND USE

Recent forest harvesting is thought to have altered the hydrologic regime of a few of the tributary watersheds, namely Lambly, Naswhito, Naramata, Bellevue and Mission Creeks, based on the percentage of the total watershed harvested since 1980. Potential effects include increased peak flows, greater runoff in most months, and increased summer low flows. Watershed assessments indicate that Lambly Creek has a high peak flow hazard, Naramata Creek, a moderate one and Naswhito and Mission Creeks, low ones.

Both Naramata and Kelowna Creeks have considerable impervious area in their watersheds as a result of urban development. However, this development is concentrated at low elevations, which contribute little to the annual runoff or peak flows of these streams. Consequently, urbanization is thought to have an insignificant effect on the flow in the main stream, although it may greatly alter flows in some small, low-elevation tributaries and cause scour in the main stream near the junction of these tributaries. Water quality from urban storm runoff is thought to potentially have a greater effect on habitat than altered water quantity.

7.5 AGGRADATION AND SEDIMENTATION

Several of the tributaries are aggrading their lower reaches, on their fans. Both Naramata and Mission Creeks have had gravel removal programs as part of flood control and channel management. A brief review of coarse sediment sources is included in a Watershed Assessment for Mission Creek by Dobson Engineering Ltd (1998c).

Sedimentation – deposition of fine material in the streambed gravels -- is reported in Kelowna and Lower Vernon Creeks as well as in a few other tributaries to Okanagan Lake. Sedimentation may result from reduction of peak flows by storage in some of these watersheds.

In most tributaries, neither the sources of coarse sediment, the causes of sedimentation of streambeds, nor alternate management strategies appear to have been investigated in detail. A detailed assessment and evaluation of approaches to reduce coarse and fine sediment supply would be valuable in Mission Creek watershed as well as in other affected watersheds.

7.6 TECHNICAL RECOMMENDATIONS

7.6.1 NATURAL FLOWS AND DEMANDS

Natural flows in the tributaries to Okanagan Lake were estimated from adjustment of complete or partial gauging records or from regional analysis. The estimated flows are of variable quality and additional hydrologic studies are warranted, particularly for the most sensitive streams, to confirm the flow estimates. Continuous flow measurements are typically not available for the small and moderate-sized tributaries that appear to have the greatest potential demands on their instream flows. We recommend continuing the miscellaneous summer low flow measurement program on these streams (see Kirk 2000; Cassidy 2001). We would also recommend adding winter flow measurements and collecting continuous stage records on two or three of the most critical streams over the summer and fall. These records would be most valuable if storage volumes, changes in storage, and licensed extractions were also measured.

We also recommend re-constructing natural flow hydrographs in one or two critical tributaries, through a program of measuring reservoir releases, reservoir levels, tributaries inflows, actual extractions, and watershed outflows. Such a program is expensive but could perhaps be undertaken in conjunction with a local Water District or environmental association with a particular interest in that watershed. Such a program would also help develop reservoir-operating regimes that best benefit fish habitat while meeting flow demands. Candidate watersheds include Trout, Trepanier, Lambly, Short, and Penticton Creeks.

As well, the relationship between actual and licensed withdrawals is not known for most types of licences and the year-to-year variation in demand is not well known. Further investigations of demands would help to better evaluate natural low flows.

7.6.2 GROUNDWATER LOSSES AND INFLOWS

We recommend low flow gauging programs along the lower reaches of tributaries that are known to be or suspected to be groundwater effluent. These programs would determine rates of loss to groundwater and sites where flows disappear subsurface. Stream deepening, gravel removal or construction of deep instream or off-channel pools for survival habitat may be options to help address losses to groundwater.

It would also be helpful to evaluate subsurface geology and groundwater movement in major aquifers and determine removals by wells as part of a program to assess potential impacts on low flows in the tributaries to Okanagan Lake.

7.6.3 STORAGE OR RESERVOIR MANAGEMENT

Development of additional storage is one option to supplement low flows, assuming that the releases can be transmitted to the lower reaches utilized by Kokanee and Rainbow Trout without either losses to groundwater or diversion for licensed demand. An alternative to developing additional storage is to modify the operation of existing reservoirs. In some watersheds it may be possible to supplement winter low flows by drawing down reservoirs when adequate snowpacks to refill the reservoirs are expected over the winter. Detailed hydrologic studies are generally required as part of such a change in operation.

7.6.4 URBANIZATION

Little is known of the effects of urbanization on Kelowna and Naramata Creeks. It is thought, but not confirmed, that urban development has little or no effect on the hydrograph of the main streams. However, further study would be warranted of changes in hydrology that result from urbanization and might result from further expansion of Kelowna and other municipalities along Okanagan Lake. Certainly, additional study of the potential effects on water quality and sedimentation are warranted.

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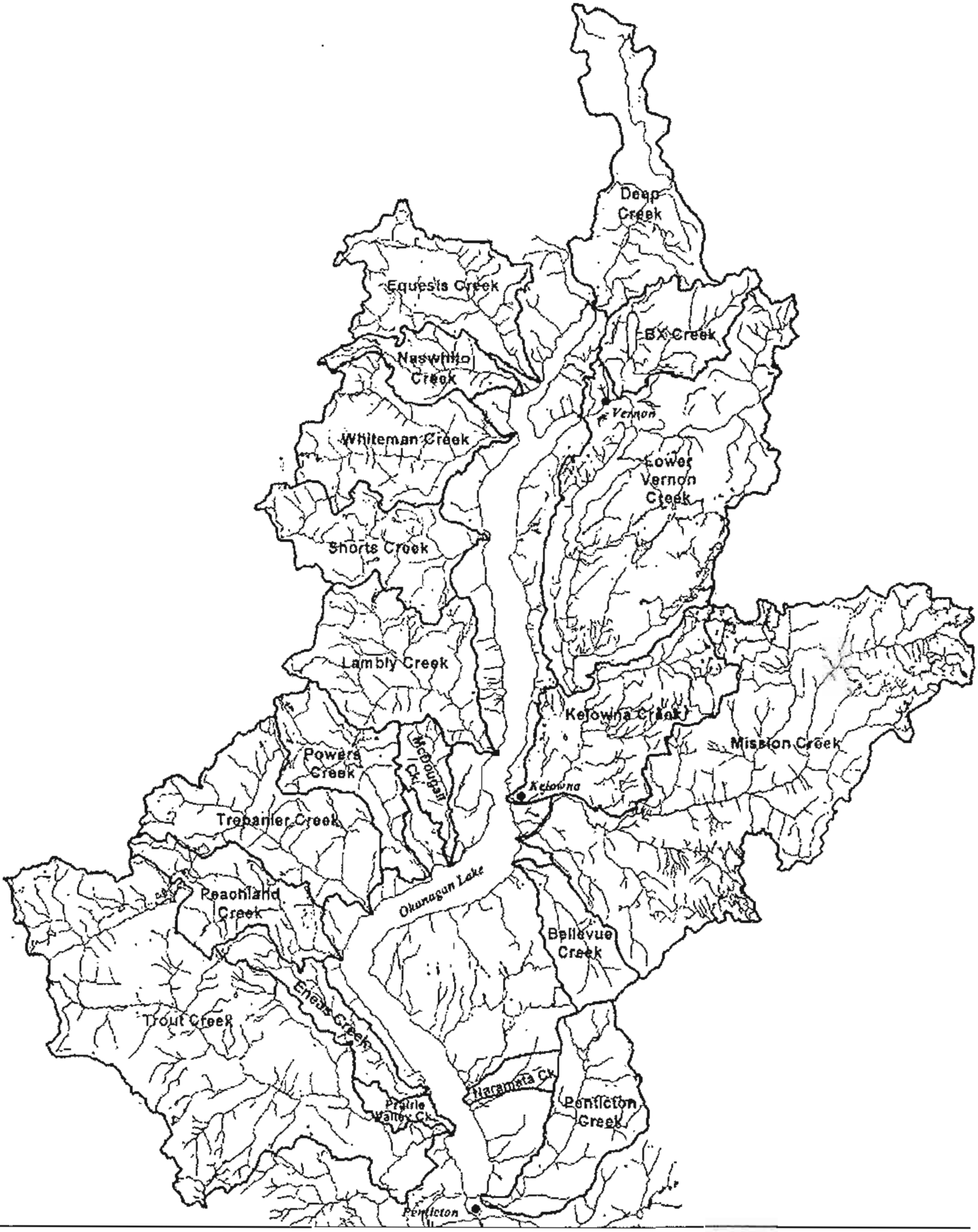

Legend

River, Stream

Lake

Okanagan Lake Study Basins

Scale - 1:400,000

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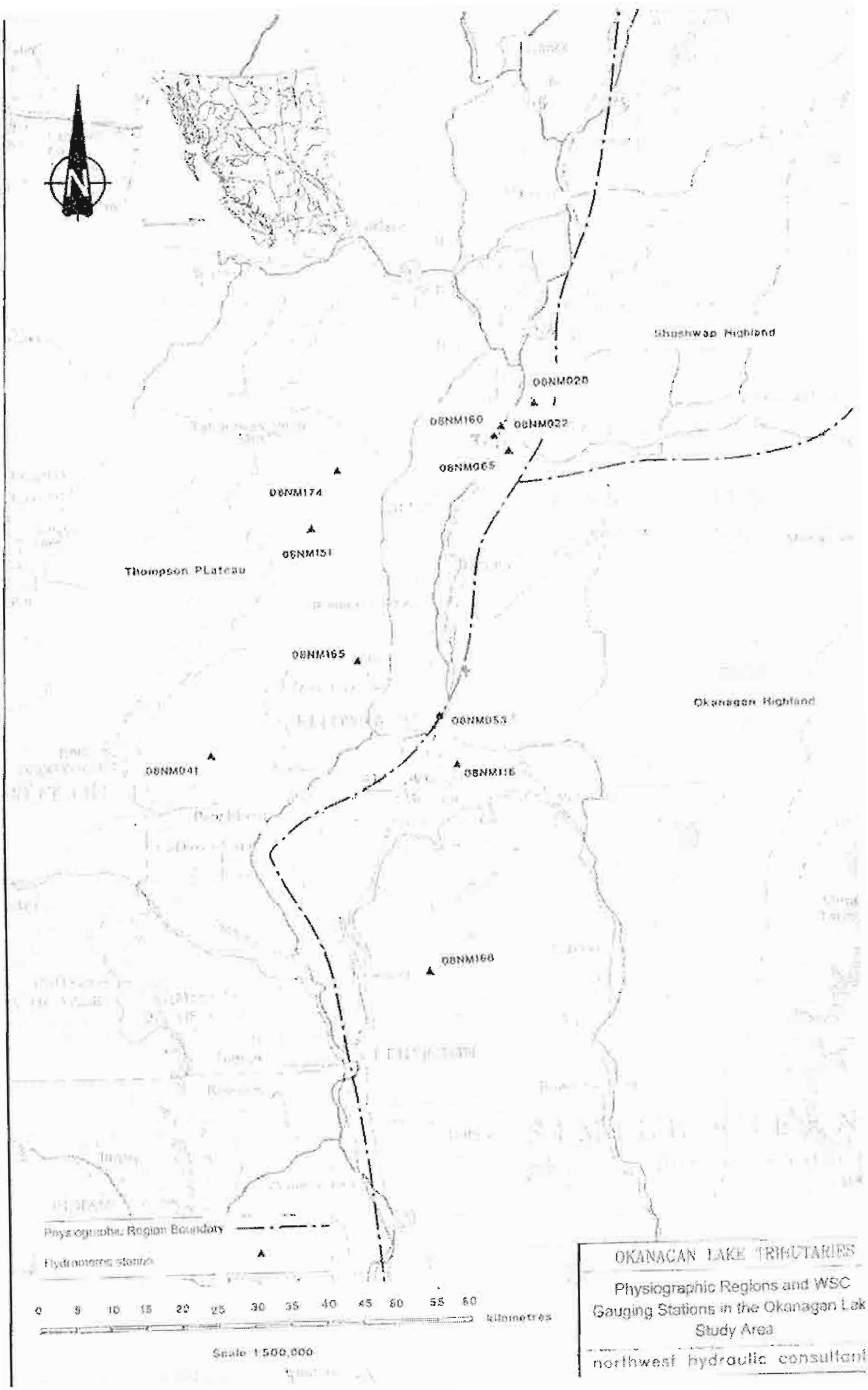
Shushwap Highland
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Physiographic Region Boundary
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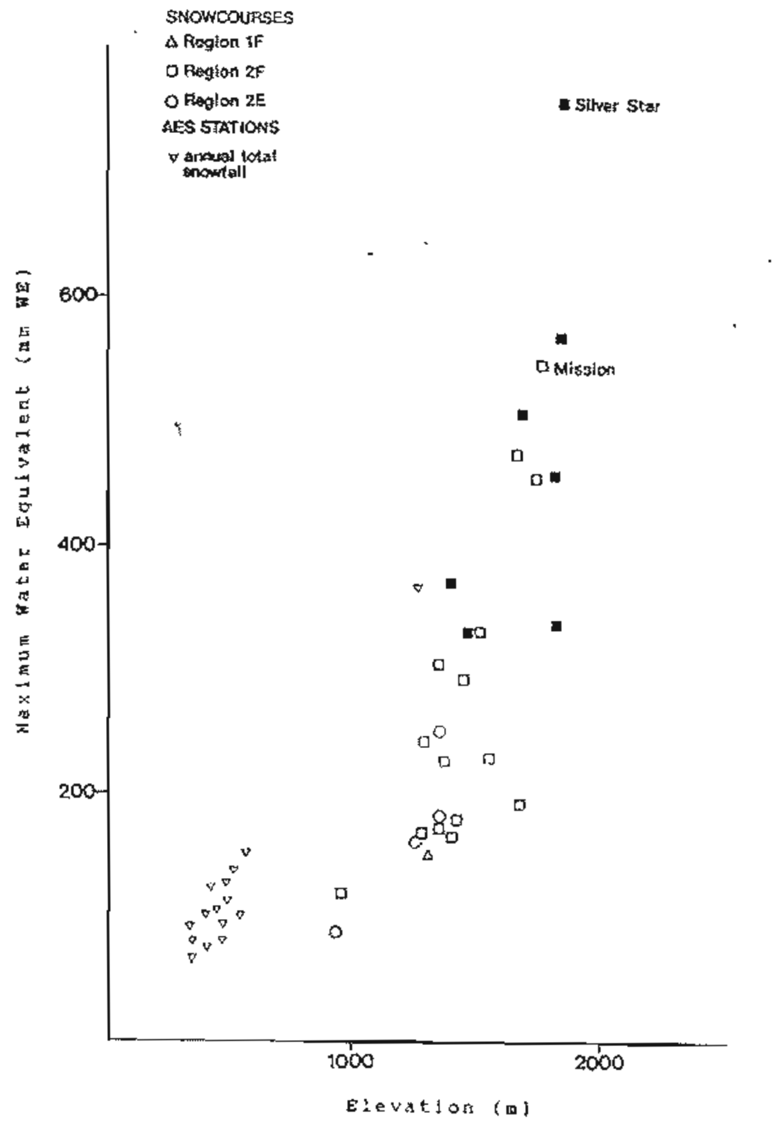
OKANAGAN LAKE TRIBUTARIES
Physiographic Regions and WSC Gauging Stations in the Okanagan Lak Study Area
northwest hydraulic consultant

Figure 2



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OKANAGAN LAKE BASIN
Maximum Normal Water Equivalent versus Elevation for the Okanagan and Surrounding Regions
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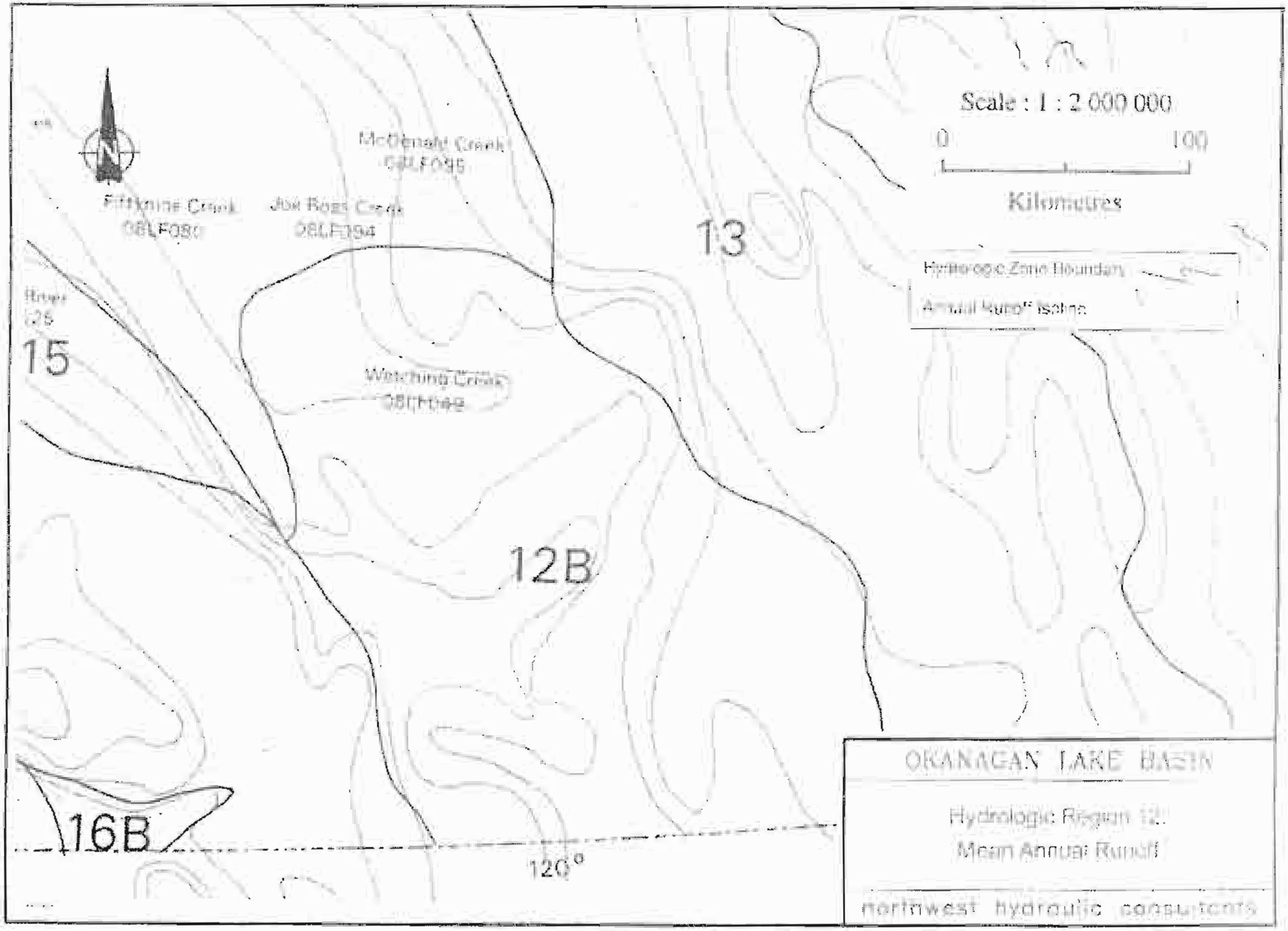
Figure 3



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Joe Ross Creek
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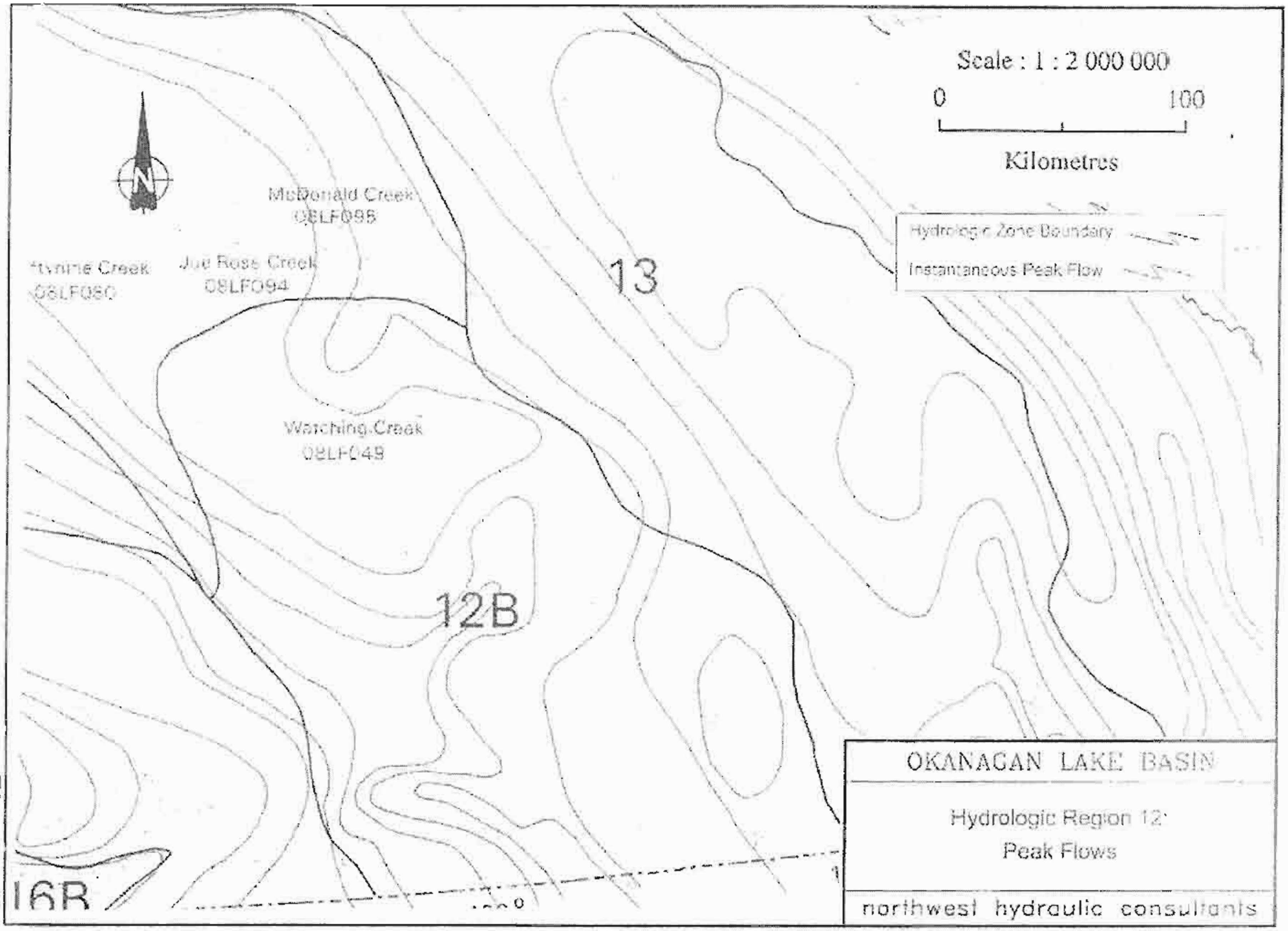
OKANAGAN LAKE BASIN
Hydrologic Region 12
Mean Annual Runoff
northwest hydraulic consultants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Hydrologic Zone Boundary
Instantaneous Peak Flow
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Watching Creek
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OKANAGAN LAKE BASIN
Hydrologic Region 12:
Peak Flows
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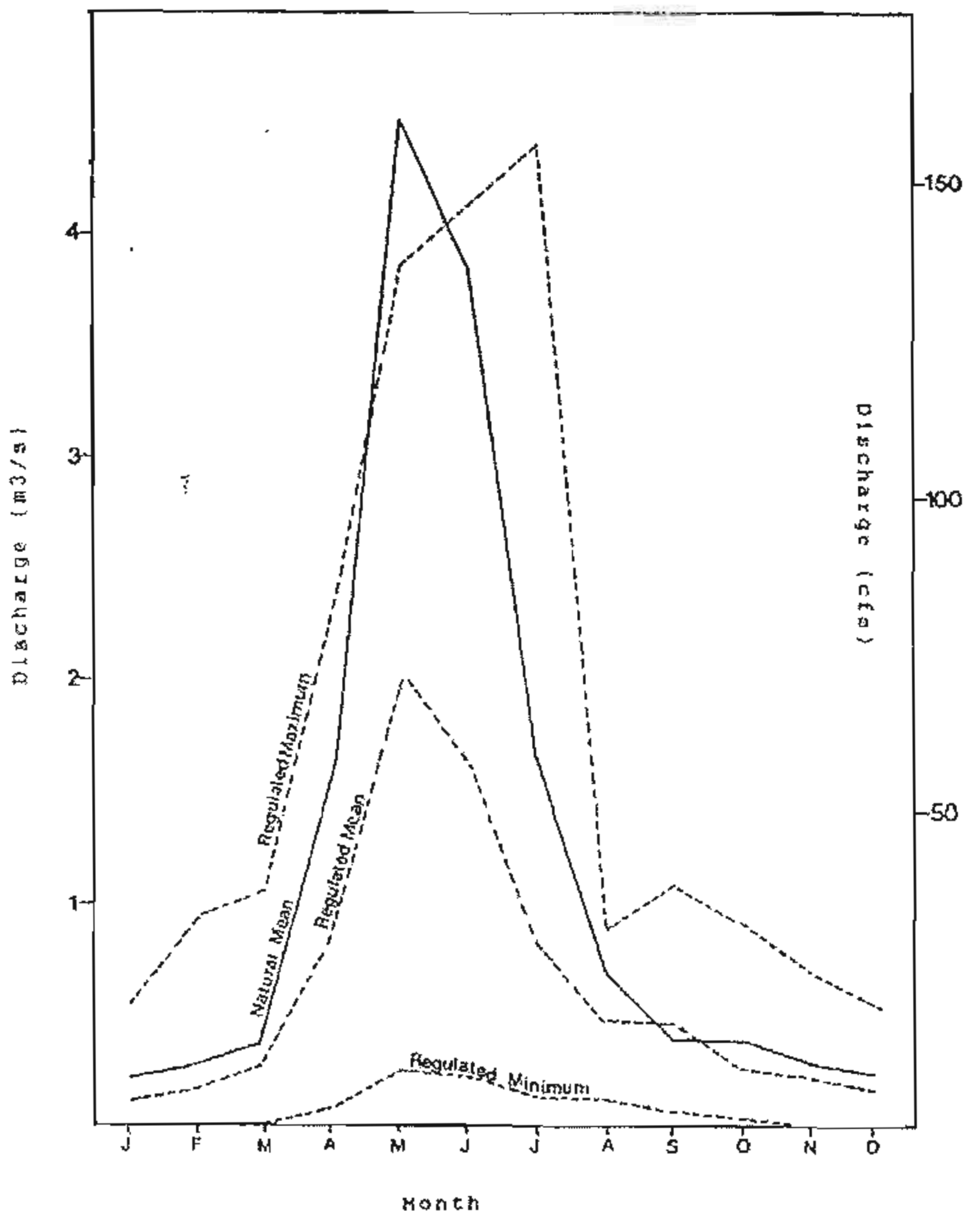
Figure 5



OKANAGAN LAKE BASIN

Natural and Regulated Monthly
Flow Regime: Duteau Creek
1975 to 1988

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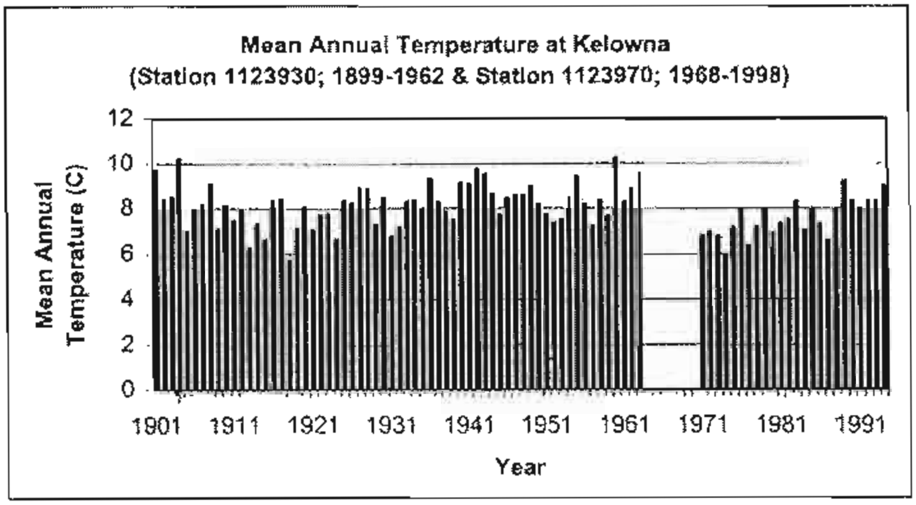
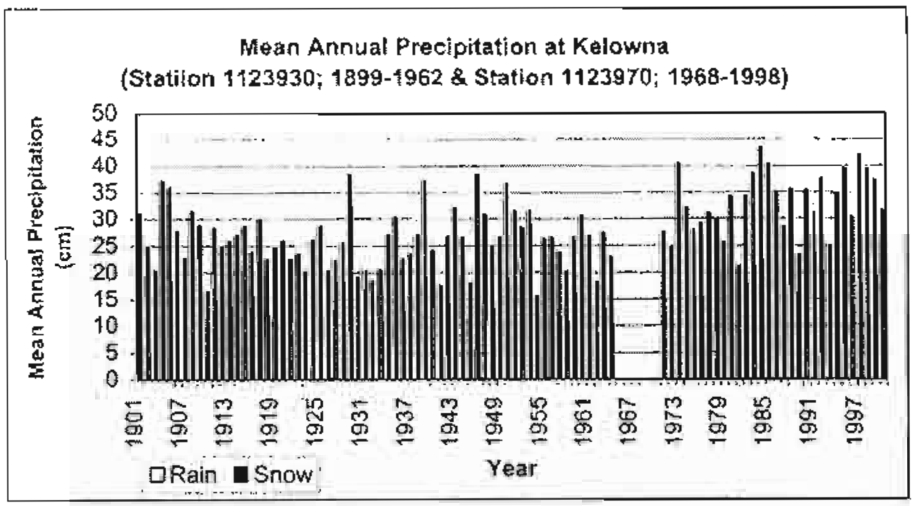
Figure 6





OKANAGAN LAKE BASIN

Long-Term Temperature
and Precipitation Trends:
Kelowna

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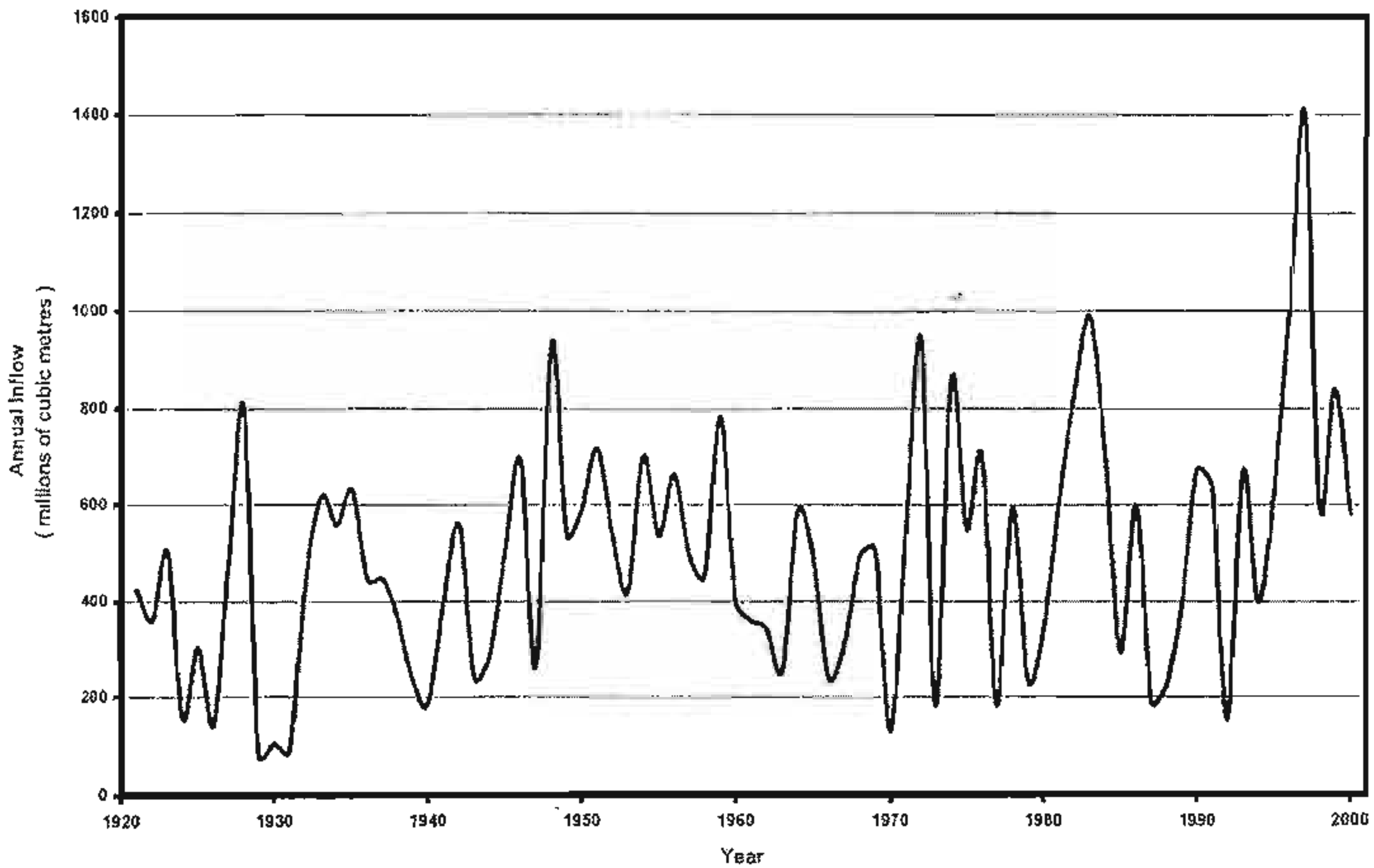
Figure 7



OKANAGAN LAKE BASIN

Long-Term Inflows to Okanagan Lake

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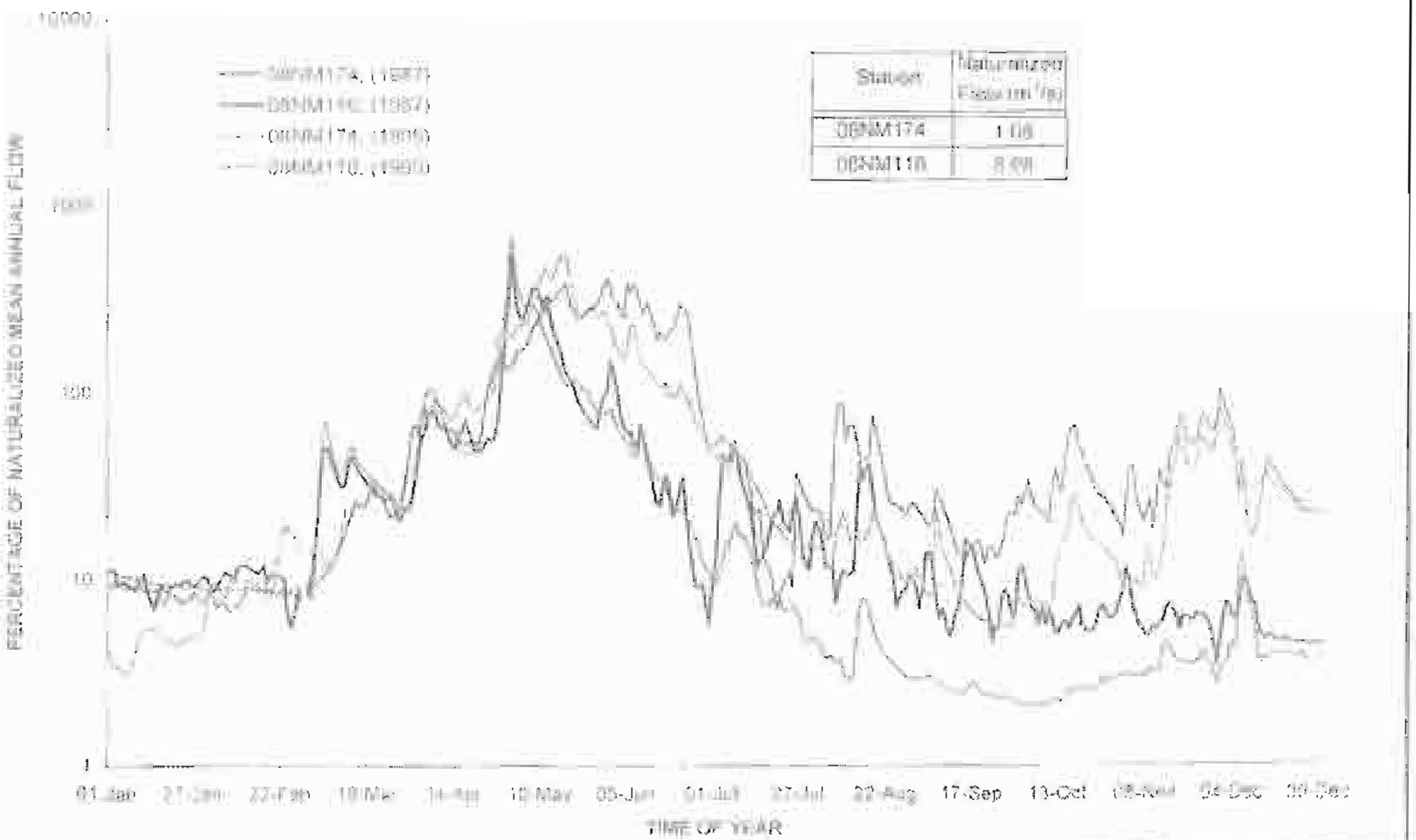
Figure 8



OKANAGAN LAKE BASIN

Hydrographs for Mission Creek near East Kelowna (08NM116) and Whiteman Creek above Bouleau Creek (08NM174)

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Figure 6

Table 1: Study Tributaries to Okanagan Lake

Stream Name	Stream No.[1]	Water Survey Data: Gauge Name	Gauge No.	Drainage Area (km^2)	Watershed Area to the mouth[2] (km^2)	Years of Record[3]	Regulated or Natural Flow
Tributaries draining from the West							
1. Trout Ck.	31-2902	below Thirsk Lake	08NM237	unreported	756.8	75 M#, 79 RS, 80 RC, 85 R?,	regulated
		near Faulder	08NM054	704		21 #, 22-27 MS, 35-54 MS	regulated
		Near Summerland	08NM042	756		20-22 MS, 28 #	regulated
		at the Mouth	08NM158	754		69-73 MC, 74 MS, 75-82 MC	regulated
2. Prairie Valley Ck.	-				27.0		
3. Eneas Ck	31-4300	near Summerland	08NM228	57.8	69.6	74-75 MS	regulated
4. Peachland Ck.	31-5000	below Diversions	08NM201	74.6	146.7	73 MS	regulated
		near Peachland	08NM029	127		19-22 MS	regulated
		above Diversions	08NM140	122		66-72 MS, 73-75 MC, 77-82 RC	regulated
		at the Mouth	08NM159	146.7		69-82 MC	regulated
		Diversion to Peachland Lake	08NM219	unreported		75-79 MS	regulated
		Lake Reservoir Outflow	08NM202	60.3		73-74 MS, 75-82 RS	regulated
		Municipal Irrigation Diversion	08NM030	unreported		19-23 MS, 24 #, 26 #	regulated
5. Trepanier Ck.	31-5300	near Peachland	08NM041	170	256.7	19-29 M#, 60-72 MS, 73-74 MC, 75-79 RC, 80-82 #, 83-99 RC	regulated
		at the mouth	08NM155	254		69-81 MC	regulated
6. Powers Ck.	31-5700	above Westbank Diversion	08NM033	128	144.9	20-22 MS, 28-29 #, 65 MS, 67-74 MS	natural
		below Westbank Diversion	08NM095	136		12 #, 24-27 RS, 65-81 MC, 82-84 RS, 85-87 RC	regulated
		at the Mouth	08NM157	144		69-74 MC, 75 MS, 76-82 MC	regulated
		Westbank Diversion	08NM034	unreported		10 #, 20-31 MS	regulated
7. McDougall Ck	31-5900	near Westbank	08NM014	55.9	52.7	20-26 RS, 28-29 #	regulated
8. Lambly Ck	31-6900	above Terrace Creek	08NM185	78.1	241.5	70-96 RC	regulated
		below Terrace Creek	08NM141	207		67-71 MS	regulated
		near Kelowna	08NM058	240		10 #, 24-25 RS, 27 RS	regulated
		below Bald Range Creek	08NM126	226		70-82 RC	regulated
		near the Mouth	08NM133	272		10 #, 19-21 MS, 65-66 MS, 69-71 MC, 75 MS	regulated
		Lake Diversion to Powers Ck.	08NM136	unreported		65-66 MS, 67 #, 68 MS, 69 #, 70-72 MS	regulated
		Diversion to Rose Valley Lake	08NM157	unreported		70-78 RC	regulated
9. Shorts Ck.	31-8300	at the Mouth	08NM161	185	185.2	69-76 MC, 77-82 RC	regulated
10. Whiteman Ck.	31-9000	above Bouleau Creek	08NM174	112	212	70 #, 71-99 RC	natural
		near Vernon	08NM046	197		11#, 20-21 MS, 49-59 MS, 60 MC, 61-65 MS, 66-67 MC, 69-70 M#	regulated
		at the Mouth	08NM169	197		70-72 MC	regulated
11. Naswhito Ck.	310-958000	near Ewing's Landing	08NM047	81.8	86.2	12 #, 20 #, 21 MS	natural
12. Equesis Ck.	31-9400	near Vernon	08NM024	179	199.5	11 M#, 20 M#, 21-22 MS, 23-28 RS	regulated
		near the Mouth	08NM161	198		59 M#, 70-72 MC, 73-74 M#, 77-82 MC	regulated

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when not available, the Watershed code is given

2 - area calculated using BC Watershed Atlas, and GIS.

3 - #-misc. measurements, M-manual gauge, R-recording gauge, S-seasonal operation, C-continuous operation

Table 1: Continued

Stream Name	Stream No [1]	WSC Gauge Data: Gauge Name	WSC Gauge Data: Gauge No.	WSC Gauge Data: Drainage Area (km²)	Watershed Area to mouth [2] (km²)	Years of Record [3]	Regulated or Natural Flow
Tributaries draining from the East							
13. Penticton Ck.	31-3500	above Dennis Creek	08NM168	35.5	184.3	70-99 RC	regulated
		below Harris Creek	08NM170	153		70-81 RC	regulated
		above Diversion	08NM070	unreported		10 #, 35 #, 36-41 MS	natural
		below Diversion	08NM031	unreported		19 #, 20-21 MS	regulated
		at the Mouth	08NM118	177		50-53 MS, 54 M#, 55 MS, 65 66 MS, 69-72 MC	regulated
		Main Diversion	08NM032	unreported		19-66 MS	regulated
		Lot 15 Diversion	08NM063	unreported		26-54 MS	regulated
14. Naramata Ck.	31-4100				38.2		
15. Bellevue Ck.	31-6200	near Okanagan Mission	08NM035	73.3	93	11 M#, 20-21 MS, 50-57 MS 68 RS, 69-56 RC	natural
		at the Mouth	08NM156	79.8		69-72 MC	regulated
16. Thompson Bk.	31-7085						
17. Mission Ck.	31-6300	above Pearson Creek	08NM233	233	844.7	77-82 RC	regulated
		below B.M.I.D. Intake	08NM239	unreported		80 RS	regulated
		near Rutland	08NM016	622		10-12 #, 18-27 MS, 37-41 MS, 42-46 MC	regulated
		near East Kelowna	08NM116	811		49-66 MS, 67 MC, 68-99 RC	regulated
18. Kelowna Ck.	31-6600	near Rutland (Upper Station)	08NM026	57.3	250.7	11-12 #, 20-22 MS	regulated
		near Rutland	08NM001	77.7		24-31 MS	regulated
		at Rutland Station	08NM117	162		50-54 MS, 70-75 MC	regulated
		near Kelowna (Lower Station)	08NM053	221		22 MS, 50-67 MS, 68 MC, 69 99 RC	regulated
19. Lower Vernon Ck. (including B.X. Ck.)	31-8100	at Outlet of Swalwell Lake	08NM020	62.4	748.5	21-30 MS, 45-46 MS, 60-67 MS, 68 RS, 69-99 RC	regulated
		below Aberdeen Dam	08NM175	102		72-79 RC	regulated
		near Okanagan Centre	08NM043	90.1		19-22 MS, 23-25 #, 26-30 MS, 60-63 MS	regulated
		at Inlet to Ellison Lake	08NM162	127		69-70 M#, 71 MS, 72-74 RC	regulated
		at Outlet of Ellison Lake	08NM182	136		71-74 RC	regulated
		above Diversions	08NM008	60.7		19 MS	regulated
		at Inlet to Wood Lake	08NM009	151		19-21 MS, 69-71 MC, 72-87 RC	regulated
		at Outlet of Kalamalka Lake	08NM065	572		27-30 MS, 59-71 MC, 72-99 RC	regulated
		at Vernon	08NM021	593		21-25 MS, 25 M#, 30-31 MS, 44-51 MS, 60 MS	regulated
		near the Mouth	08NM160	751		69-76 MC, 77-82 RC, 84-99 MS	regulated
		Diversion to W.O.C.I.D.	08NM236	unreported		73-78 RC	regulated
		Okanagan Centre Diversion	08NM044	unreported		19 MS, 21 #, 22-31 MS, 60-63 MS	regulated
20. - BX Ck.	31-8100-050	above Vernon Intake	08NM020	55.7	130.7	21-27 MS, 59-75 MC, 76-97 RC	regulated
		above Swan Lake Control Dam	08NM125	unreported		59-79 MC	regulated
		below Swan Lake Control Dam	08NM123	120		10 #, 59-66 MC, 67-69 #, 70 MC, 71 #, 72 MS, 73-78 MC	regulated
21. Deep Ck.	31-8600	at Young Road	08NM177	115	245.4	70-75 MC	natural
		at Armstrong	08NM119	135		51-59 MS, 60 MC, 61-63 MS, 64-67 #, 74-82 MC	regulated
		near Vernon (Station No. 3)	08NM075	207		30-32 #, 35-50 MS, 65-67 M#	regulated
		at the Mouth	08NM153	306		69-76 MC	regulated

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3153-200-46

Table 2: Physiography and Ecoregions in the Okanagan Lake Basin

Stream Name	SSIS Number	Total Drainage Area (km^2)	Physiographic Region	Ecoregions	Ecosections
Tributaries draining from the West					
1.Trout Ck.	31-900	762	TP	T-O P	OKB/STU
2. Prairie Valley Ck.	-	14	TP	T-O P	OKB
3. Eneas Ck.	31-4300	101	TP	T-O P	OKB
4. Peachland Ck.	31-5000	159	TP	T-O P	OKB/STU
5. Trepanier Ck.	31-5300	252	TP	T-O P	OKB/STU
6. Powers Ck.	31-5700	169	TP	T-O P	OKB/STU
7. McDougall Ck.	31-5900	53	TP	T-O P	OKB
8. Lambly Ck.	31-6900	238	TP	T-O P	OKB/STU
9 Shorts Ck.	31-8300	191	TP	T-O P	OKB
10. Whiteman Ck.	31-9000	213	TP	T-O P	OKB/STU
11. Naswhito Ck.	310-958000	89	TP	T-O P	OKB
12. Equesis Ck.	31-9400	202	TP	T-O P	OKB/STU
Tributaries draining from the East					
13. Penticton Ck.	31-3500	183	OH	T-O P	OKH
14. Naramata Ck.	31-4100	29	TP&OH	T-O P	OKH
15. Bellevue Ck.	31-6200	95	TP&OH	T-O P	OKH
16. Thompson Bk.	310-7965000	-	TP&OH	T-O P	OKH
17. Mission Ck.	31-6300	916	TP&OH	T-O P	OKH
18. Kelowna Ck.	31-6500	261	TP&OH	T-O P	OKB/OKH
19. Lower Vernon Ck.	31-9100	748	TP&SH	T-O P	OKB/OKH
20. - BX Ck.	31-9100-050	126	TP&SH	T-O P	OKH
21. Deep Ck.	31-9800	242	TP&SH	T-O P	ETU/OKB

TP - Thompson Plateau
OH - Okanagan Highland
SH - Shushwap Highland
T-O P - Thompson-Okanagan Plateau

OKB - Okanagan Basin
OKH - Okanagan Highland
ETU - Eastern Thompson Highland
STU - Southern Thompson Highland

Table 3: Selected Climate Stations in the Okanagan Watershed

Climate Station [1]	Ecosection [2]	Physiographic Region [2]	Latitude	Longitude	Elevation (m)	Normal Precipitation (mm) [3]				Mean Annual Temperature	Period of Record
						Annual	May to Sept	Annual Snowfall	Greatest Daily		
Osoyoos	OKH	OH	49.02	119.26	297	340.2	136.2	67.3	40.9	10.0	1954-91
Osoyoos West	OKH	OH	49.02	119.26	297	303.6	123.4	53.8	46	9.9	1967-98
Oliver STP	OKB	TP	49.01	119.33	297	307.8	130.2	57.1	55	9.9	1924-98
Oliver	OKB	TP	49.01	119.33	315	301.1	128.3	51.5	61	9.1	1938-98
Okanagan Falls	OKB	TP	49.19	119.33	335	281.4	103.1	68.6	40.6	--	1965-68
Beaverdell	OKH	OH	49.25	119.06	768	472.2	176.8	246.5	34.3	--	1925-98
Penticton A	OKH	OH	49.28	119.36	344	308.5	142.1	73	44.5	8.9	1941-98
Summerland CDA	OKB	TP	49.34	119.39	454	291.1	126.5	77.7	45.5	8.9	1916-95
Summerland CDA EL	OKB	TP	49.34	119.38	346	276.5	123.1	68.7	39.1	9.3	1949-64
Peachland	OKB	TP	49.46	119.43	424	324.8	114.7	122.1	33.5	9.0	1971-98
Peachland Brenda Mines	OKH	TP	49.52	120.00	1520	634.6	207.4	391.4	45	2.9	1968-93
McCulloch	OKH	TP	49.48	119.12	1250	702.6	277.2	370.3	43.2	2.8	1923-96
Kelowna Lakeview	OKB	TP	49.51	119.34	427	330.2	128.8	121.2	33	8.8	1952-98
Joe Rich Creek	OKH	TP	49.51	119.08	875	579.4	274.4	172.9	63.5	4.6	1928-98
Kelowna CDA	OKB	TP	49.52	119.25	485	322.7	131.9	96.7	33.5	7.7	1950-70
Kelowna OK college	OKB	TP	49.52	119.29	350	329.7	142.7	83.6	34.4	8.6	1969-98
Kelowna Bowes Street	OKB	TP	49.53	119.28	351	318	128.7	80.7	32	8.7	1961-69
Kelowna	OKB	TP	49.54	119.28	354	332.2	136.3	96.9	63.5	-	1899-62
Kelowna A	OKB	TP	49.58	119.23	429	312.4	139.1	103.5	33.4	7.2	1968-98
Winfield	OKB	TP	50.02	119.25	503	332.2	141.4	106.2	37.6	8.2	1971-98
Okanagan Centre	OKB	TP	50.04	119.27	347	355.5	147.8	80.8	43.7	8.6	1925-98
Oyama	OKB	TP	50.07	119.22	396	386.6	168.9	91.4	39.6	7.8	1965-97
Lumby	OKH	SH	50.15	118.58	509	420.3	192.6	143.2	37.3	6.5	1959-98
Lumby Sigalet Rd	OKH	SH	50.22	118.46	560	547.4	248.3	157	32.3	--	1970-98
Vernon	ETU	TP	50.14	119.17	555	347.7	150.6	102.8	29.5	7.9	1971-94
Vernon Coldstream Ranch	ETU	TP	50.14	119.12	482	447.4	204.8	123.3	55.9	7.5	1900-97
Westwold	OKB	TP	50.28	119.03	610	352.5	172.2	92.9	36.3	6.1	1921-98
Salmon Arm	ETU	SH	50.42	119.15	506	533.7	202.1	175.8	49.5	7.6	1911-82
Salmon Arm 2	ETU	SH	50.42	119.17	396	530.9	195.2	159.4	42.9	7.8	1950-86

1. Climate stations are listed from south to north.
2. OKH is Okanagan Highland, OKB, Okanagan Basin, and ETU Eastern Thompson Upland. OH is Okanagan Highland, TP, Thompson Plateau and SH, Shuswap Highland.
3. Climate normals are from 1961 to 1990, where available; otherwise they are from 1951 to 1980.

Table 4: Channel Stability in the Okanagan Lake Tributaries

	Channel Response						Human Modifications							
TRIBUTARY	Pattern Change	Erosion	Incision	Aggradation	Bed Material Scour	Sedimentation	Diking	River Training	Encroachment	Gravel Removal	Vegetation Removal	Add Spawning Gravel	Settling Basins	Debris Removal
Tributaries draining from the West														
1.Trout Ck.														
2. Prairie Valley Ck.														
3. Eneas Ck.														
4. Peachland Ck.		●			●	●			●	●		●	●	
5. Trepanier Ck.									●					
6. Powers Ck.					●							●		●
7. McDougall Ck.														
8. Lambly Ck.		●			●			●				●		
9. Shorts Ck.				●										
10. Whiteman Ck.														
11. Naswhito Ck.														
12. Equesis Ck.														
Tributaries draining from the East														
13. Penticton Ck.							●	●				●		●
14. Naramata Ck.				●			●			●				
15. Bellevue Ck.														
16. Thompson Bk.						●								
17. Mission Ck		●		●		●		●		●				
18. Kelowna Ck.						●			●			●	●	●
19. Lower Vernon Ck.		●				●		●				●		
20. - BX Ck.														
21. Deep Ck.														

Table 5: Fish Periodicity Chart for Mission Creek, Kelowna, British Columbia

Species	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Flow Standard (%mad)
Ecological Needs/Issue													
Fish food production	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	20%mad; Riffle maintenance
Wetland/trib linkage				XXXX	XXXX	XXXX	XXXX						100
Flushing/Channel Maintenance					XXXX	XXXX							>400 for several days on alternative years
Stream Temps>7 C					XXXX	XXXX	XXXX	XXXX	XXXX	XXX			May 1-Oct.21
Icing (Code = B)	XXXX	XXXX										XXX	1997 reference year
Hydrology [1]													
Nat monthly flow (%mad)	**17**	**22**	**31**	**131**	**374**	**318**	**134**	**57**	**34**	**33**	**25**	**21**	
Mean Monthly Flow (%mad)	13%	13%	18%	69%	283%	275%	75%	27%	33%	28%	23%	15%	
Conservation Flow (%mad)	20%	[illegible]	20%	[illegible]	71%	71%	55%	20%	20%	20%	20%	20%	Highest per event in month
Observed Mean Flows (L/s)	**1050**	**1010**	**1480**	**5560**	**22900**	**22200**	**6030**	**2160**	**2630**	**2230**	**1840**	**1240**	
Observed Min Monthly (L/s)	[illegible]	[illegible]	507	1180	10700	3150.0	921	732	[illegible]	533	408	450.0	Note: 1987 a very dry year!!!
Observed Min Monthly (%MAD)	4%	[illegible]	8%	[illegible]	134%	[illegible]	12%	9%	[illegible]	7%	[illegible]	6%	%mad values
Rainbow Trout (stream and migratory lake pops)													
Smolt/migrant passage					XXXX	XXXX							50
Adult passage				XX	XXXX	XXXX							71 for days-weeks
Spawning					XX	XXXX							71 for days-weeks
Incubation					XX	XXXX	XX						20
Emergence							XX	X					
Rearing (juveniles)					XXXX	XXXX	XXXX	XXXX	XXXX	XXX			20; 174 days where temps>7 degrees C
Rearing (adults)					XXXX	XXXX	XXXX	XXXX	XXXX	XXX			55; 174 days where temps>7 degrees C
Over-wintering	XXXX	XXXX	XXXX	XXXX						XXXX	XXXX(	XXXX	20
Kokanee Salmon													
Smolt/migrant passage				XXXX	XXXX								50
Adult passage									XXXX				20%mad or 1600 L/s; riffle coverage; min passage flow of 11-14%mad or 850 to 1130 L/s
Spawning									XXX	XXXX			
Incubation	XXXX	XXXX	XX						XXX	XXXX	XXXX	XXXX	20
Emergence			XX	XXXX									
Rearing			XX	XXXX									

1. Mission Creek Naturalized Mean Annual Discharge (mad in L/s) = 8080 L/s at WSC Station 08NM116

Table 6: Definitions of Flow Characteristics

Annual Flood	Maximum or "peak" daily flow of the year.
Annual Flow	Average of the daily flows between January 1 and December 31 for a particular year.
Annual 7 day low flow	The lowest average flow for 7 consecutive days between January 1 and December 31. Same as "7 day mean low".
Daily flow	Average flow for the period midnight to midnight.
Mean Annual Flood	Average of the annual floods for a stated historic period.
Mean Annual Flow	Average of the annual flows for a stated historic period.
Mean Annual 7 day low flow	Average of the 7 day low flows for a stated historic period.
Mean August flow	Average of the August flows for a stated historic period.
Mean September flow	Average of the September flows for a stated historic period.
Mean summer 7 day low flow	Average of the summer 7 day low flows for a stated historic period.
Mean winter 7 day low flow	Average of the winter 7 day low flows for a stated historic period.
Naturalized flow	Measured flows, adjusted with upstream water licenses, to represent the flows that would occur in the absence of regulation and extraction.
Summer 7 day low flow	The lowest average flow for 7 consecutive days between May 1 and October 31.
Water Demand	Sum of all the consumptive uses upstream of a reference point, as estimated from water licenses.
Winter 7 day low flow	The lowest average flow for 7 consecutive days between November 1 and April 30.
Unit Flow	The flow at a reference point, usually a Water Survey of Canada station, divided by the basin area above that reference point.

Table 7: Hydrology of the Tributaries to Okanagan Lake

Stream Name	WSC Gauge Number [4]	Subzone [5]	Basin Area (mouth) (km^2)	Harvest as a Percentage of Watershed [1]					Licensed Demand (L/s) [2]			Estimated Natural Flows (m^3/s) [3]						
														Mean Monthly			Mean 7-day Flow	
				Pre-1980	1980-1989	1990-1999	2000	Unknown	Aug	Sept	Jan	Mean Annual	Mean Flood	Aug	Sept	Jan	Summer	Winter
Tributaries draining from the West																		
1.Trout Ck.		b	759	8.0%	6.7%	4.2%	0.1%	11.5%	200	81	2	2.65	25	0.92	0.75	0.44	0.40	0.29
2. Prairie Valley Ck.		b	27	-	-	-	-	-	0	0	0	0.02	0.5	0.01	0.005	0.003	0.003	0.002
3. Eneas Ck.		b	90	2.1%	0.0%	0.0%	0.0%	7.1%	112	44	0	0.17	9.4	0.06	0.05	0.03	0.03	0.02
4. Peachland Ck.	NM159	b	149	6.1%	1.2%	7.0%	0.0%	13.1%	0	0	0	0.57	2.7	0.25	0.25	0.11	0.15	0.08
5. Trepanier Ck.	NM155	b	257	6.8%	1.0%	2.0%	0.0%	14.1%	167	103	61	1.15	13	0.34	0.23	0.16	0.13	0.12
6. Powers Ck.		b	145	9.1%	4.3%	6.4%	0.0%	7.4%	134	78	42	0.92	8.9	0.32	0.26	0.15	0.21	0.13
7. McDougall Ck.		b	53	2.9%	1.3%	0.4%	0.0%	13.4%	56	56	56	0.12	4.5	0.04	0.03	0.02	0.02	0.01
8. Lambly Ck.		e	242	20.8%	13.2%	0.9%	0.0%	15.9%	0	0	0	1.77	22	0.61	0.50	0.29	0.10	0.12
9. Shorts Ck.	NM151	e	185	10.6%	4.2%	5.0%	0.0%	4.9%	0	0	0	1.30	13	0.23	0.18	0.08	0.06	0.03
10. Whiteman Ck.	NM046	e	212	9.7%	5.4%	5.2%	0.0%	4.7%	75	30	0	1.28	10	0.40	0.33	0.15	0.25	0.14
11. Naswhito Ck.		e	88	4.8%	14.5%	8.6%	0.0%	6.0%	95	38	0	0.31	7.4	0.11	0.09	0.05	0.05	0.03
12. Equesis Ck.	NM161	e	200	11.4%	4.8%	2.5%	0.0%	11.3%	142	57	1	0.70	5.6	0.37	0.27	0.15	0.19	0.08
Tributaries draining from the East																		
13. Penticton Ck.		b	184	4.3%	0.2%	7.1%	0.2%	1.7%	0	0	0	1.35	11.9	0.47	0.38	0.22	0.20	0.15
14. Naramata Ck.		b	30	9.9%	6.1%	11.5%	0.0%	6.9%	361	151	12	0.10	1.5	0.03	0.03	0.02	0.01	0.01
15. Bellevue Ck.	NM035	b	93	0.6%	8.4%	9.6%	0.0%	8.5%	10	4	0	0.42	5.8	0.07	0.05	0.02	0.03	0.02
16. Thompson Bk.		b	-	-	-	-	-	-	0	0	0	-	-	0.005	0.005	-	-	-
17. Mission Ck.		c	845	5.0%	12.5%	3.4%	0.0%	8.7%	1264	536	55	8.08	59	4.61	2.75	1.37	1.32	1.09
18. Kelowna Ck.	NM053	e	261	3.4%	3.3%	2.4%	0.0%	13.3%	215	88	4	1.16	4.4	0.69	0.62	0.32	0.33	0.25
19. Vernon Ck.		c	748	4.6%	6.4%	2.0%	0.0%	5.7%	1652	1127	780	3.34	7.5	1.90	1.14	0.57	0.43	0.34
20. - BX Ck.		c	131	1.8%	2.0%	0.6%	0.0%	20.3%	397	265	177	0.67	3.3	0.38	0.23	0.11	0.10	0.07
21. Deep Ck.	NM153	c	245	3.8%	1.2%	1.9%	0.0%	10.8%	224	160	118	0.55	2.2	0.35	0.35	0.43	0.26	0.34

1. Harvesting data provided by Ministry of Forests, expressed as percentage of total watershed area.
2. Licensed demand calculated from water licences above the basin mouth, as described in the main body of the text. Land Improvement licenses are not included in the demands.
3. Natural flow characteristics calculated by regional analysis, naturalization or from previous studies, as described in Appendix A. Mean annual floods are based on recorded flows and have not been naturalized.
4. Flow characteristics naturalized from WSC records if gauge number is shown. See Appendix A for details.
5. Subzone designations are from Obedkoff (1998).

Table 8: Urban Development in the Okanagan Lake Basin

Stream Name	SSIS Number	Drainage Area (km^2)	% EIA [1]	EIA (km^2) [2,3,4]	Urban Development			
					Low Density (km^2)	Medium Density (km^2)	High Density (km^2)	Commercial Industrial (km^2)
Kelowna Ck.	31-6500	260.7	2.8%	7.28	1.1	3.2	1.5	7.2
Bellevue Ck.	31-6200	93	0.4%	0.41	0.096	1.95	0.44	0.003
Naramata Ck.	31-4100	30.2	7.9%	2.39	0	2.2	0.032	2.5
Deep Ck.	31-9800	245.4	0.7%	1.69	0.147	3.09	0	1.6
B.X. Ck.	31-9100-050	130.7	0.7%	0.89	0.27	0.64	0.22	0.82
Powers Ck. [5]	31-5700	144.9	0.0%	0.06	0.86	0.29	0	0
Peachland Ck. [5]	31-5000	148.7	0.0%	0.03	0.46	0.15	0	0
Vernon Ck. [5]	31-9100	748.3	0.2%	1.4804	5.63	0.75	0.04	1.35

1. %EIA calculated by dividing the total effective impervious area of the basin by the basin drainage area
2. Assumes Total Impervious Area is 10%-Low, 20%-Medium, 35%-High, 90%-Commercial/Industrial
3. Assumes that Effective Impervious Area is 40% of total for Low density, 50% of total for Medium density, 80% of total for High density, 95% of total for Commercial/Industrial.

4. The resulting EIA is calculated by multiplying 2x3x area of each urban development: 4%-Low, 10%-Med, 23%-High, 86%-Commercial/Industrial.
5. For Powers creek and Peachland creek: the urban area values are from the Regional District of Central Okanagan OCP. Estimated zoning types are 75% Low Density, 25% Med Density. For Vernon creek: zoning of several surrounding townships are estimated from 1:50,000 NTS maps and Regional District of Central Okanagan OCP. Low density development is assumed except where it is specifically indicated to be multifamily or commercial/industrial.

Table 9: Classification of BC Water Licences

No.	Use Class	Description (uses included)	Units
	CONSUMPTIVE		
1	Waterworks	-conveyed by local authority (munipality, regional or improvement district) to more than 5 dwellings	gallons/day
		-conveyed by others (individual, utility, Indian band)	gallons/year
2	Domestic use	-water use for up to four dwellings, gardens to ¼ acre, stock watering	gallons/day
3	Pulpmills	-water for processing	cubic feet/second
4	Industrial	-processing (sawmills, food, manufacturing, etc.) -cooling -enterprise (hotels, motels, restaurants, etc.) -ponds -watering -bottling for sale -commercial bulk export -mineral water sold in containers and used in bathing pools -all other industrial uses	any
5	Irrigation	-conveyed by Water District or other authority or private individual -use on cultivated lands or hay meadows	acre-feet
6	Land improvement	e.g. draining property, creating ponds	any
7	Mining	-hydraulic, washing coal, processing ore, placer	any
	NON-CONSUMPTIVE		
8	Power generation	-residential, commercial, general	cubic feet/second
9	Storage - nonpower	-storage for purposes other than power generation	acre-feet
10	Storage - power	-storage for power production	acre-feet
11	Conservation	-storage (e.g. waterfowl habitat enhancement) -use of water (e.g. hatchery) -construction of works in and around a stream (e.g. fish culture, fish ponds, personal)	any

Table 10: Licensed Storage and Demands in the Tributaries to Okanagan Lake

	Licensed Withdrawals [1]					*Licensed NonPower Storage* [1]				*Licensed Demand* [2]			
Stream Name	Domestic (gals/day)	Irrigation (acre-feet)	Waterworks (gals/day)	Industrial (gals/day)	Conser-vation (cfs)	Other Storage (ac-ft)	Irrigation Storage (ac-ft)	Waterworks Storage (gals/day)	Conser-vation Storage (ac-ft)	Total Annual Demand (m^3/s)	Adjusted August Demand (L/s)	Adjusted September Demand (L/s)	Adjusted January Demand (L/s)
Tributaries Draining from the West													
1.Trout Ck.	13,650	15,741	838,562	14,000	-	-	14,018	833,562	-	0.66	200	81	2
2. Prairie Valley Ck.	-	-	-	-	-	-	-	-	-	-	-	-	-
3. Eneas Ck.	-	3,524	-	1,001	3.00	1,462	1,099	-	-	0.14	112	44	0
4. Peachland Ck.	3,500	2,477	2,853,113	1,300	11.45	6,014	1,416	-	-	0.25	-	-	-
5. Trepanier Ck.	36,000	1,577	1,044,718	10,313	-	-	657	1,500	120	0.12	167	103	61
6. Powers Ck.	2,500	4,272	1,467,049	-	3.00	770	2,706	724,760	-	0.24	134	78	42
7. McDougall Ck.	7,750	716	-	1,285,057	-	911	194	-	-	0.10	56	56	56
8. Lambly Ck.	4,500	5,145	4,439,479	6,000	-	9,417	2,823	2,176,289	-	0.44	-	-	-
9. Shorts Ck.	4,000	294	-	256,716	0.01	2,000	-	-	-	0.03	0	0	-
10. Whiteman Ck.	6,500	650	-	-	-	-	-	-	-	0.03	75	30	0
11. Naswhito Ck.	2,000	822	-	-	-	-	-	-	-	0.03	95	38	0
12. Equesis Ck.	8,500	3,364	-	2,000	0.06	892	1,253	333	-	0.13	142	57	1
Tributaries Draining from the East													
13. Penticton Ck.	1,000	4,519	4,020,000	327,789	-	7,753	1,521	1,659,122	-	0.41	0	0	-
14. Naramata Ck.	1,000	3,070	211,000	-	-	-	50	-	-	0.13	361	151	12
15. Bellevue Ck.	-	92	-	-	2.00	1.1	3.3	-	-	0.00	10	4	-
16. Thompson Bk.	-	-	-	-	-	-	-	-	-	-	-	-	-
17. Mission Ck.	41,750	48,599	4,129,411	680,999	7.95	-	38,150	3,869,411	0.25	2.16	1,264	536	55
18. Kelowna Ck.	10,000	13,006	312,500	41,674	10.83	-	11,182	297,500	-	0.53	215	88	4
19. Lower Vernon Ck.	94,450	22,489	22,009,215	767,517	6.51	1,996	12,953	8,942,379	2,265	2.08	1,652	1,127	780
20. - BX Ck.	8,500	2,254	5,252,500	5,072	0.01	-	352	2,100,500	2,264	0.37	397	265	177
21. Deep Ck.	11,200	1,414	89,000	2,089,414	-	-	493	89,000	-	0.17	224	160	118
Total	248,300	131,770	41,414,047	5,483,780	44.81	31,216	88,516	18,593,856	2,385	7.63	4,708	2,555	1,130

1. Licensed withdrawals and licensed storage are the totals above the mouth of each stream. Information obtained from Type #2 reports from the Ministry of Environment, Lands and Parks Water Rights Information System. Storage is divided in irrigation, waterworks and non-power as described in the report.
2. Licensed demand calculated for the mouth of each stream from withdrawals adjusted for associated storage, as described in the main body of the report

Table 11: Sensitivity Indices for the Tributaries to Okanagan Lake

Stream Name	*Gauge* [1]	*Summer Water Use* [2]				*Low Flows* [2]		*Peak Flows* [2]	*Logging* [2]	
		Index 1 Actual Aug/Q_{AA}	Index 2 Actual Sept/Q_{AA}	Index 3 Aug Use/Aug	Index 4 Sept Use/Sept	Index 5 $SQ7L_2$/ Q_{AA}	Index 6 $WQ7L_2$/ Q_{AA}	Index 7 Q_2/Q_{AA}	Index 8 Recent/ Basin Area	Index 9 Total/ Basin Area
Tributaries draining from the West										
1.Trout Ck.	NM158	14%	12%	22%	11%	15%	11%	928%	11%	30%
2. Prairie Valley Ck.		--	--	0%	0%	15%	11%	--	0%	0%
3. Eneas Ck.		--	--	188%	91%	15%	11%	--	0%	9%
4. Peachland Ck.	NM159	44%	44%	0%	0%	26%	14%	482%	8%	27%
5. Trepanier Ck.	NM155	15%	11%	50%	46%	12%	10%	1163%	3%	24%
6. Powers Ck.	NM157	29%	27%	42%	30%	22%	14%	966%	11%	27%
7. McDougall Ck.		--	--	137%	169%	15%	11%	--	2%	18%
8. Lambly Ck.	NM003	5%	4%	0%	0%	6%	7%	1250%	14%	51%
9. Shorts Ck.	NM151	17%	13%	0%	0%	4%	2%	965%	9%	25%
10. Whiteman Ck.	NM046	28%	26%	19%	9%	22%	12%	896%	11%	25%
11. Naswhito Ck.		--	--	88%	44%	15%	11%	--	23%	34%
12. Equesis Ck.	NM161	33%	30%	38%	21%	27%	11%	793%	7%	30%
Tributaries draining from the East										
13. Penticton Ck.	NM118	10%	19%	0%	0%	15%	11%	880%	8%	14%
14. Naramata Ck.		--	--	1080%	556%	15%	11%	--	18%	34%
15. Bellevue Ck.	NM035	14%	11%	15%	8%	7%	4%	1404%	18%	27%
16. Thompson Bk.		--	--	--	--	--	--	--	0%	0%
17. Mission Ck.	NM116	29%	33%	27%	20%	16%	13%	735%	16%	30%
18. Kelowna Ck.	NM053	41%	45%	31%	14%	28%	22%	378%	6%	22%
19. Vernon Ck.	NM160	34%	24%	87%	99%	13%	10%	224%	8%	19%
20. - BX Ck.	NM123	28%	27%	104%	117%	15%	11%	495%	3%	25%
21. Deep Ck.	NM153	24%	34%	63%	46%	47%	62%	405%	3%	18%

1. Water Survey of Canada (WSC) gauge numbers used for calculating actual August and September flows. See text for details.
2. Actual Aug and Sept are estimated actual flows for these two months calculated from WSC gauging records near the stream mouths. Aug and Sept Use are net demands in these months; $SQ7L_2$ and $WQ7L_2$ are summer and winter mean 7 day low flows; Aug and Sept are mean August and September monthly flows; Q_{AA} is mean annual flow; Q_2 is the mean annual instantaneous flood, Recent and total refer to area logged in the watershed; basin is total watershed area.
3. All indices expressed as percentages.

Table 12: Most Sensitive Streams [1]

Less Than Conservation Flows	Water Demand	Summer Low Flows	Winter Low Flows	Peak Flows	Urbanization	Forest Harvesting
Indices 1 & 2	*Indices 3 & 4*	*Index 5*	*Index 6*	*Index 7*	-	*Indices 8 & 9*
Trout Creek	Naramata Ck	Shorts Ck	Shorts Ck	***Scour***	Naramata Ck	Lambly Ck
Trepanier Creek	Eneas Ck	Lambly Ck	Bellevue Ck	***(High Indices)***	Kelowna Ck	Naswhito Ck
Lambly Creek	McDougall Ck	Bellevue Ck	Lambly Ck	Lambly Creek		Naramata Ck
Shorts Creek	B.X. Creek	Trepanier Ck	Trepanier Ck	Bellevue Creek		Bellevue Ck
Penticton Creek	Nashwhito Ck	Lower Vernon Ck		Trepanier Creek		Mission Ck
Bellevue Ck				***Sedimentation***		
				(Low Indices)		
				Lower Vernon Ck		
				Kelowna Creek		
				Peachland Creek		
				Deep Creek		

1. Criteria for selection described in the main body of the report.

A. ESTIMATING NATURAL FLOWS

A.1 INTRODUCTION

The Water Survey of Canada has gauged most of the tributaries to Okanagan Lake; however, none of the tributaries has a continuous record at its mouth over the period from 1961 to 1995 that can be used to calculate its natural flow characteristics. Consequently, these characteristics must be estimated by regional hydrologic analysis, from analyses in other reports, by naturalization and adjustment of flow records from gauges near the mouth, or by transfer from upstream gauges (Table A1).

Obedkoff (1998) completed the most recent regional analysis for the area surrounding Okanagan Lake, predicting mean annual runoff and 10-year return period instantaneous maxima for five subzones. He also included regional curves for summer and annual 10-year return period 7-day low flows. To extend his analysis, we selected 17 gauging stations from his subzones 12b, 12c and 12e that had natural flow (Table A2). These stations had complete or nearly complete records over the base period from 1961 to 1995, with watershed areas greater than 10 km^2 but less than 144 km^2. Flow characteristics, watershed areas and median elevations are summarized in Table A1 (see Coulson and Obedkoff 1998). Most of these watersheds lie at high elevations around the rim of the Okanagan Lake Valley.

Regression of natural flow characteristics on physiography resulted either in relationships that were not statistically significant or ones that predicted flows at the mouths of the tributaries that did not agree with measured flows. The poor results at the mouths of the tributary streams are thought to result from the unusual distribution of the streams and from extrapolation beyond the range of watershed areas included in the data set. Efforts at additional regional hydrologic analysis to predict natural flow characteristics at the mouths of the tributaries were abandoned.

We adopted several different approaches to estimate the various natural flow characteristics. A considerable effort was put into estimating mean annual runoff, as described in the following Sections A.2. Where practical, we have relied on naturalization of Water Survey of Canada records to estimate natural flow characteristics. However, for ungauged streams, a variety of other techniques were adopted to estimate natural flow characteristics, as described in the following sections.

A.2 MEAN ANNUAL RUNOFF (FLOW)

At least three techniques are available to estimate mean annual flow (runoff) in the Okanagan Lake tributaries. Letvak (1980a; 1980b) developed regression equations that relate natural runoff for a particular year to watershed characteristics such as area, median elevation, distance to a barrier and a latitude index. Separate equations were prepared for the west side and east side tributaries, with the equations for the west side tributaries involving second and third orders of the physiographic variables. The runoff is predicted for a particular year, which is then adjusted to a long-term mean through a regional frequency curve for annual runoff at WSC gauges. Estimates of mean annual flow are thereby adjusted to the 1965 to 1978 historic period. Later analysis suggested that updating the regional frequency curve gauges had little effect on the long-term estimates (Letvak 1994). Various reports by Letvak (1983a; 1984; 1989) quote long-term mean annual runoff for the larger tributaries to Okanagan Lake often calculated from his regional equations.

As part of predicting flows, we calculated areas and median elevations for the watersheds above the mouths of many of the tributaries to Okanagan Lake (Table A3). Also, in order to utilize existing regression equations (i.e. Letvak 1980a & b) we calculated elevation indices, distances to the generalized 2,500-foot contour and latitude indices for the watersheds above the mouths of some of the tributaries. These data are not reported.

The standard error is about 15 mm (0.6 inches) for the equation for the west side tributaries and about 40 mm (1.5 inches) for the east side tributaries. The equations are biased and they predict annual runoff of less than zero for watersheds with low median elevations. They are not recommended for median elevations of less than about 1,200 m or so; as a result, they cannot be applied to Eneas, Thompson, Prairie Valley or Vernon Creeks. The equations also predict negative runoff when applied to Naswhito Creek and near-zero runoff when applied to Kelowna (Mill) Creek. Table A3 summarizes the mean annual runoffs predicted by applying Letvak's equations to some of the tributary watersheds.

The second procedure is to use a graphical relationship between median elevation and annual runoff for subregions 12b, 12c, and 12e to estimate annual runoff for the tributary watersheds from Obedkoff (1998). His graphs are based on natural mean annual flow for the 1961 to 1995 normal period, as described in Coulson and Obedkoff (1998). The predictive curves can be extrapolated to median elevation of less than 1,000 m and consequently can be used to prepare estimates for the low elevation tributaries.

The third procedure is to naturalize gauging records at the mouths of the tributaries with total licensed demands. First, reported mean annual flows at the WSC gauges were adjusted to the 1961 to 1995 period by multiplying them by the average inflow to Okanagan Lake over the period of record at the gauge, divided by the average inflow to Okanagan Lake from 1961 to 1995. After this adjustment, flows were converted to runoff and the annual demand (expressed as a runoff) added (Table A3). As described in the main report, actual water use is usually less than licensed demand; consequently this approach is likely to over-estimate natural mean annual flows.

Table A3 summarizes our recommended mean annual runoffs for the tributaries to Okanagan Lake. Often, we have adopted a compromise between the estimate derived by naturalizing WSC records and other estimates.

Regional estimates for Eneas Creek seemed far too low when compared to the limited gauging records; consequently, the mean annual runoff as increased above that calculated from Obedkoff (1998).

A.3 MEAN ANNUAL FLOOD

Two approaches were used to estimate mean annual instantaneous maxima. First, the regional analysis of Obedkoff (1998) was adjusted to predict mean annual instantaneous floods. He provided curves relating 10-year instantaneous maxima to watershed area for each of his subzones, which can be expressed a

$$Q_{10} = C * A^{0.785} \quad (1)$$

Where Q_{10} is the ten-year instantaneous maxima, expressed in m^3/s, and A is watershed area in km^2. The coefficient C is calculated to be 0.37 in subze 12e, 0.71 in subzone 12b and 0.83 in subzone 12c. Ratios of 2-year to 10-year instantaneous floods seem to average about 0.6. Consequently, the above equation (1) was applied to the tributary watershed with a coefficient of 0.22 for those in subzone 12e, 0.43 for those in subzone 12b, and 0.50 for those in subzone 12c. Applying Equation (1) over-predicted peak flows at the mouths of the tributaries by about a factor of two, when compared to observed streams with natural flow, such as Shorts and Whiteman Creeks.

The second approach was based on analysis of the reported mean annual floods in Table A2. For these streams, watershed area was significantly correlated with mean annual flood; median elevation showed little independent correlation. The correlation with watershed area was strongest with untransformed variables. The constant and coefficient for the linear regression equation, relating mean annual flood to watershed area are shown in the following table:

Variable	Constant	Coefficient	R^2	SE_y	N
Mean Flood	-2.44	0.132	0.82	--	17

The above equation over-estimates mean annual floods for the very small and very large watersheds, again by a factor of about two. (The log-log regression produced a coefficient (exponent) greater than 1 and it greatly over-estimates floods in the large tributaries.)

Consequently, we have calculated the mean annual flood from measured annual maxima at the Water Survey of Canada gauges. Mean annual instantaneous floods were calculated directly from WSC gauging records, where instantaneous measurements are available. Where they are not, daily mean annual floods were adjusted to instantaneous values with an instantaneous to daily (I/D) ratio of 1.09, based on Shorts Creek at the mouth (08NM151) and other natural gauges. Mean annual floods were then adjusted to the 1961 to 1995 period following the procedure described in Section A.2. It is recognized that storage may greatly reduce peak flows in some watersheds and the quoted values may often be less than natural floods.

For ungauged streams the second approach (above) was adopted to predict mean annual floods. The mean annual flood in Prairie Creek was estimated to be 0.5 m^3/s. No prediction was provided for Thompson Brook.

A.4 MEAN MONTHLY FLOWS

For tributaries with WSC gauges near their mouths and little or no storage in their watersheds (less than 10% of mean annual flow), reported mean monthly flows for August, September and January were adjusted to the 1961 to 1995 period following the procedure described in Section A.2. They were then naturalized with the licensed demands from Table 7, for the following streams:

- *Peachland Creek at the mouth (08NM159):* Flow characteristics calculated from this record were naturalized with licensed demands above the mouth. They were assumed to represent natural flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. Monthly flows in late summer are a large portion of the mean annual flow. Peachland Creek has an unusual annual hydrograph that is much less "peaky" than most nearby streams (Appendix B).

- *Trepanier Creek at the mouth (08NM155):* Flow characteristics calculated from this record were naturalized with licensed demands above the mouth. They were assumed to represent natural flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. Monthly flows seem to be a very low percentage of mean annual flow at this gauge, possibly as a result of losses to groundwater in the lowermost reaches.

- *Shorts Creek at the mouth (08NM151):* Flow characteristics calculated from this record are natural flows. They are assumed to represent flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. No adjustment has been incorporated for the reported losses to groundwater in the low 0.25 km of this stream.

- *Whiteman Creek near Vernon (08NM046) and Whiteman Creek near the mouth (08NM180)*: Flow characteristics calculated from these records were naturalized with licensed demands above the mouth. They were assumed to represent natural flows at the mouth, as the additional watershed area between the gauge and the mouth is at low elevation and is thought to contribute little flow. No adjustment has been incorporated for losses to groundwater. Despite the missing data at the gauge and older flow records we preferred the naturalized flow records to estimates from other approaches.

- *Equesis Creek near the mouth (08NM161):* Flow characteristics calculated from this record were naturalized with licensed demands to the mouth. They were assumed to represent natural flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. No adjustment has been incorporated for losses to groundwater in the lower reaches.

- *Bellevue Creek near Okanagan Mission (08NM035):* Flow characteristics calculated from this natural record were assumed to represent natural flows at the mouth as the additional watershed area to the mouth lies at low elevations and is thought to contribute little flow to the creek. No adjustment has been incorporated for losses to groundwater in the lower reaches. Comparison of overlapping records at the gauges near Okanagan Mission (08NM035) and at the mouth (08NM156) shows little reduction in flows in August and September but large losses in January. The apparent losses in January may result from gauging errors, flows to groundwater, or unrecorded water use.

- *Deep Creek at the mouth (08NM153):* Flow characteristics calculated from this record were naturalized with licensed demands to the mouth. They were assumed to represent natural flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. Monthly flows in late summer at the gauge at the mouth are a greater percentage of mean annual flow than at upstream gauges (at Armstrong, 08NM119 and at Young Road, 08NM177). This is assumed to result from groundwater inflows to Deep Creek along the lower valley above Okanagan Lake. Note that reported January flows are greater than those in the late summer (see Appendix B).

Mean monthly flows were also adjusted and naturalized for Kelowna Creek, despite significant storage in the watershed, as it was felt that the %mean monthly flow method described below was not adequate to characterize its regime:

- *Kelowna Creek near Kelowna (Lower Station) (08NM053):* Flow characteristics calculated from this record were adjusted to the 1961 to 1995 period and naturalized with licensed demands to the mouth. They were then adjusted to the mouth based on the ratio of watershed areas at the mouth and at the gauge (1.18). Flows were adjusted because it is thought that groundwater inflows increase flows at the mouth above those recorded at the gauge.

Mean monthly flows, expressed as percentage of mean annual flow, were not well correlated with either watershed area or median elevation. Consequently, average natural or naturalized monthly flows, expressed as a percentage of the mean annual flow, were adopted to predict natural monthly flows for the tributaries not discussed above. The percentages observed in Duteau Creek were used for watersheds on the east side of Okanagan Lake near Vernon in subzone 12c – B.X., Vernon, Kelowna and Mission Creeks. Rood (1989) provides further details on the Duteau Creek Watershed (see also Section 2). For the remaining watersheds lying in subzones 12b and 12e, the average %monthly flows reported in Table A2, expressed as percentage of mean annual flow, have been adopted for predicting natural mean monthly flows. The coefficients of variation around the averages quoted in Table A2 are about 30% for each of the three months.

A.5 SEVEN DAY LOW FLOWS

Obedkoff (1990) reports natural and observed summer and winter 7 day low flows, at a five-year return period, for Peachland, Trepanier, Powers, Mission, Kelowna and Lower Vernon Creeks. He naturalized daily WSC gauging records, then adjusted estimated low flows to the mouth by prorating by watershed area or by plotting estimates at various gauges and extrapolating the general trend along the main stream. The records cover various periods but his natural 7 day low flows are roughly representative of the 1965 to 1990 period. He generally classified his estimates as "poor" or "tentative".

We have adopted some of his estimates for the above streams, adjusting them to mean annual 7 day low flows. Based on a review of annual 7 day low flow frequency analyses for gauges on the tributaries, the typical ratio of the five-year flow to the two-year one is 0.68. Consequently, we multiplied Obedkoff's estimates by 1.47 to adjust to mean annual values before adding them to Table 7. We did not adopt his estimate for Lambly Creek as the large storage volumes and the two diversions from the watershed are thought to result in unreliable estimates from naturalizing gauge records. We also did not adopt his estimates for Peachland Creek, as they seemed to be much larger than observed flows at the gauge at the mouth. Instead we naturalized the observed flows as described below.

Reported mean annual summer and winter 7 day flows were adjusted to the 1961 to 1995 period following the procedure described in Section A.2 for the following streams. Summer 7 day low flows were then naturalized with licensed demands from September; winter ones with licensed demands from January (Table 7).

- *Shorts Creek at the mouth (08NM151):* Flows at the gauge are natural flows assumed to be representative of those at the mouth, as there is almost no additional watershed area between the gauge and the mouth. No adjustment has been incorporated for the known losses to groundwater in the low 0.25 km of this stream. Note that annual minimums mostly occur in winter at this gauge.

- *Whiteman Creek near Vernon (08NM046) and Whiteman Creek near the mouth (08NM180)*: Flow characteristics calculated from this record were assumed to represent natural flows at the mouth, as the additional watershed area between the gauge and the mouth is at low elevation and is thought to contribute little flow. No adjustment has been incorporated for losses to groundwater.

- *Equesis Creek near the mouth (08NM161):* Flow characteristics calculated from this record were assumed to represent natural flows at the mouth, as there is almost no additional watershed area between the gauge and the mouth. No adjustment has been incorporated for losses to groundwater in the lower reaches. Note that annual minimums are split between summer and winter at this gauge.

- *Bellevue Creek near Okanagan Mission (08NM035):* Flow characteristics calculated from this record are natural and were assumed to represent flows at the mouth as the additional watershed area to the mouth is at low-elevation and thought to contribute little flow to the creek. No adjustment has been incorporated for losses to groundwater in the lower reaches. Comparison of overlapping records at the gauges near Okanagan Mission (08NM035) and at the mouth (08NM156) shows little reduction in flows in August and September but large losses in January. These losses may result from gauging errors, flows to groundwater or unrecorded water use.

Mean 7 day low flows, expressed as percentage of mean annual flow, were not well correlated with either watershed area or median elevation. Consequently, 7 day low flows in Table A2 were expressed as a percentage of the mean annual flow, as were natural 7 day flow estimates by Obedkoff (1990) for Trepanier, Powers, Mission and Vernon Creeks, and averaged. Mean summer 7 day low flows averaged 15% of mean annual flow; winter ones, 11% of mean annual flow. These percentages were used to calculate natural 7 day low flows for those tributaries not discussed above, including those without stream gauging records and those with large storage volumes or major diversions where naturalization of gauging records is not thought to be effective.

A.6 MISCELLANEOUS MEASUREMENTS

Monthly flows in August and September for Thompson Brook were estimated from Kirk (2000) based on his reported miscellaneous measurements from the summer of 1999. Note that flows were well above average in 1999 at most stream gauges and the above approach likely overestimates long term monthly mean flows.

Table A1: Estimating Natural Flows for Tributaries to Okanagan Lake

Stream Name	Watershed Area (km^2)	Mean Annual Flood [1]	Mean Monthly Flows [2]	Summer 7 Day Low Flow [3]	Winter 7 Day Low Flows [3]
Tributaries draining from the West					
1.Trout Ck.	762	reported	%mean annual	%mean annual	%mean annual
2. Prairie Valley Ck.	14	estimated	%mean annual	%mean annual	%mean annual
3. Eneas Ck.	101	regression	%mean annual	%mean annual	%mean annual
4. Peachland Ck.	159	reported	naturalize	Obedkoff (1990)	Obedkoff (1990)
5. Trepanier Ck.	252	reported	naturalize	Obedkoff (1990)	Obedkoff (1990)
6. Powers Ck.	169	reported	%mean annual	Obedkoff (1990)	Obedkoff (1990)
7. McDougall Ck.	53	regression	%mean annual	%mean annual	%mean annual
8. Lambly Ck.	238	reported	%mean annual	Obedkoff (1990)	Obedkoff (1990)
9. Shorts Ck.	191	reported	naturalize	naturalize	naturalize
10. Whiteman Ck.	213	reported	naturalize	naturalize	naturalize
11. Naswhito Ck.	89	regression	%mean annual	%mean annual	%mean annual
12. Equesis Ck.	202	reported	naturalize	naturalize	naturalize
Tributaries draining from the East					
13. Penticton Ck.	183	reported	%mean annual	%mean annual	%mean annual
14. Naramata Ck.	29	regression	%mean annual	%mean annual	%mean annual
15. Bellevue Ck.	95	reported	naturalize	naturalize	naturalize
16. Thompson Bk.	-	-	-	-	-
17. Mission Ck.	916	reported	%mean annual	Obedkoff (1990)	Obedkoff (1990)
18. Kelowna Ck.	261	reported	%mean annual	Obedkoff (1990)	Obedkoff (1990)
19. Vernon Ck.	748	reported	%mean annual	Obedkoff (1990)	Obedkoff (1990)
20. - BX Ck.	126	reported	%mean annual	%mean annual	%mean annual
21. Deep Ck.	242	reported	naturalize	naturalize	naturalize

1. Mean annual floods are based on reported annual maxima or calculated from regional flood regression equations.
2. Mean monthly flows are either naturalized from WSC gauging records with licensed demand or estimated as a percentage of mean annual flow.
3. Mean 7 day low flows are either naturalized, calculated as percentage of mean annual flow or adjusted from values quoted in Obedkoff (1990).

Table A2: Natural Flow Characteristics in the Okanagan Watershed

Stream Name	Gauge #	Watershed Area	Median Elevation [1]	Mean Annual Flow [2]	Mean Annual Flood [2]	% Monthly Flow [3]			7-Day Low Flows	
						January	August	September	Summer	Winter
Bellevue Ck	08NM035	74.5	1540.0	0.39	5.50	6.4	16.1	12.6	0.031	0.018
BX Ck	08NM020	55 9	1130.0	0.30	2.63	16.0	34.5	24.3	0.034	0.021
Camp Ck	08NM134	36.5	1450.0	0.16	1.41	29.2	45.4	35.4	0.045	0.032
Clark Ck	08NM146	16.2	1360.0	0.08	0.99	7.4	27.5	19.0	0.004	0.002
Coldstream	08NM142	59.4	1120.0	0.26	2.19	21.6	41.5	32.2	0.055	0.033
Daves Ck	08NM137	33.4	1290.0	0.12	1.16	16.1	30.1	40.5	0.015	0.008
Ewer Ck	08NM176	49.1	1470.0	0.37	3.52	15.0	32.3	26.3	0.060	0.037
Greata Ck	08NM173	42.3	1280.0	0.09	0.70	30.1	51.2	37.2	0.023	0.016
Lambly Ck	08NM165	75.3	1390.0	0.57	6.11	16.4	33.2	26.9	0.115	0.057
Pearson Ck	08NM172	74.6	1560.0	0.97	8.98	13.5	43.1	46.6	0.179	0.086
Shatford Ck	08NM037	96.9	1530.0	0.39	4.48	15.4	37.9	23.3	0.059	0.038
Terrace Ck	08NM138	34.8	1490.0	0.28	3.35	10.0	21.8	21.4	0.011	0.008
Testalinden Ck	08NM164	13.0	1270.0	0.03	0.22	28.3	54.6	37.9	0.008	0.006
Trapping Ck	08NN019	144 0	1350 0	1.49	14.47	13.4	25.7	23.1	0.148	0.105
Vaseaux Ck	08NM171	116 0	1680 0	0.94	11.78	13.4	33.9	24.7	0.121	0.081
Whiteman Ck	08NM174	109.0	1450.0	0.64	7.16	14.2	26.0	20.7	0.077	0.050
AVERAGE		64.4	1397.5	0.44	4.67	16.6	34.7	28.2	0.062	0.037
STANDARD DEVIATION		37.2	154.3	0.40	4.16	7.2	10.5	9.1	0.053	0.031
COEFFICIENT OF VARIANCE		57 8%	11.0%	90.4%	89.2%	43.2%	30.4%	32.3%	86.4%	83.5%

1. From Coulson and Obedkoff (1998).
2. Average of reported annual flows or instantaneous maxima over the 1961 to 1995 period.
3. Expressed as a percentage of the mean annual flow.

Table A3: Estimates of Mean Annual Runoff from Tributaries to Okanagan Lake

Study Basin	Watershed Area [1] (km²)	Median Basin Elevation [1] (m)	Mean Annual Runoff Estimates: Regional Equations (mm)	Subzone [3]	Regional Analysis [3] (mm)	Previous Reports [4] (mm)	Naturalized Runoff [5] (mm)	Adopted Runoff
Tributaries draining from the West								
Trout Creek	759	1370	59	b	100	82	110	110
Prairie Valley Creek	27	650	unreliable	b	20	-	-	20
Eneas Creek	90	840	unreliable	b	30	-	-	60
Peachland Creek	149	1230	79	b	80	-	129	120
Trepanier Creek	257	1300	144	b	90	-	144	140
Powers Creek	145	-	-	b	-	180	207	200
McDougall Creek	53	1210	60	b	70	-	-	70
Lambly Creek	242	1300	180	e	110	-	240	230
Shorts Creek	185	1430	223	e	170	-	172	170
Whiteman Creek	212	1400	121	e	150	-	197	190
Naswhito Creek	88	1280	unreliable	e	110	-	-	110
Equesis Creek	200	-	-	e	-	102	115	110
Tributaries draining from the East								
Penticton Creek	184	1620	182	b	180	-	236	230
Naramata Creek	30	1380	60	b	100	-	-	100
Bellevue Creek	93	1480	125	b	120	-	149	140
Thompson Brook	-	-	-	b	-	-	-	-
Mission Creek	845	-	-	c	-	178	306	300
Kelowna Creek	261	1060	unreliable	e	70	-	138	140
Vernon Creek	618	920	46	c	110	-	149	140
-BX Creek	131	860	65	c	100	-	168	160
Deep Creek	245	560	unreliable	c	50	-	68	70

1. Watershed areas from watershed atlas; median elevations from 1:50,000 NTS maps.
2. Runoff estimate from regional equations in Letvak (1980a & b).
3. Hydrologic subzone and runoff estimates from maps and regional curves in Obedkoff (1998).
4. From Letvak (1983a), Letvak (1984), or Letvak (1989).
5. Reported mean annual flow at a gauge near the mouth, adjusted to the 1960 to 1995 period. Adjusted to the mouth of the stream if required and licensed demand added. Some estimates uncertain.