Cheakamus Project Water Use Plan

Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring

CMSMON-03

Effects of Cheakamus Generating Station on Discharge in Squamish River and Potential Impacts on Fish Populations

Study Period: 2018

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Executive Summary

The objective of this report is to quantify potential effects of operations at the Cheakamus Generating Station (CGS) on the magnitude and pattern of flow in the mainstem Squamish River and evaluate the potential impact on salmonids. The Cheakamus Generating Station can operate as a hydropeaking facility which introduces short duration, high and low flow discharge patterns to meet short-term variation in electricity demand. Hydropeaking operations at CGS typically occur during the winter when inflows to Daisy Lake are insufficient to run the plant at full capacity 24-hours per day. Effects of unnatural variation in flow due to hydroelectric operations on fish populations has been evaluated in a number of systems. Although there are still many unknowns, these studies have documented reduced macroinvertebrate production, increased mortality of early life stages of fish due to dewatering, and chronic effects on growth. In 2017, the Cheakamus WUP monitoring advisory committee recommended funding a review of historical records of discharge to evaluate potential impacts of CGS operations on fish populations in the Squamish River during low flow periods. This report summarizes the findings from this study.

A strong hydropeaking pattern in discharge at the Brackendale gauge on the Squamish River, located ~ 25 km downstream of CGS, was evident in winter months when natural inflows were low due to cold air temperatures. During periods when inflows are very low, the peak flow over 24 hours at this gauge is twice as large as the lowest (base) flow due to hydropeaking at the plant. This results in a daily peak-to-base flow ratio (P/B) of ~2, an associated stage changes of ~ 0.5 m, and maximum rates of stage change of 12-15 cm/hr. These latter values are well in excess of the DFO recommended guideline of -2.5 cm/hr. Maximum within-day peak-to-base flow ratios (P/B) of 1.3 to 1.5 are used to limit impacts of hydropeaking operations on fish populations in other systems. In the Squamish mainstem at the Brackendale gauge, P/B values of 1.3 and 1.5 were exceeded 61-68% and 35-49% of the time between November and March, 1984-2017, due to CGS operations. These P/B criteria are also exceeded in high flow months during the summer due to natural variation in snow and glacial melt over 24 hours. P/B values of 1.3 and 1.5 were exceeded 17-32% and 3-7% of the time between June and August, respectively. Natural diel variation in flow from snowmelt during summer is considerably less common that during winter due to CGS operations.

The effect of CGS operations on fish populations in the Squamish River is uncertain. A review of life history information for the five species of Pacific Salmon, Steelhead Trout, and Bull Trout that use the Squamish system is provided. Chinook, Pink, and Chum fry that migrate through the Squamish mainstem in February and March would be vulnerable to CGS-driven variation in flow and stage. Habitat quality for Coho, Chinook, and Steelhead trout parr that overwintering in the mainstem Squamish may also be reduced by CGS-driven fluctuations in flow and stage.

Table of Contents

1.0 Introduction

Daisy Lake Dam impounded the Cheakamus River in 1957 and created Daisy Lake Reservoir. A proportion of the water entering the reservoir is diverted through a 11 km tunnel through Cloudburst Mountain to the Squamish River for power generation at the Cheakamus Generating Station (CGS), with the remainder passing through Daisy Lake Dam to the Cheakamus River (Fig. 1a). Water from CGS is discharged into a relatively short tailrace channel which connects to a natural side channel before joining the mainstem Squamish River (Fig. 1b). The Squamish River and its tributaries support all five species of Pacific Salmon (Chinook, Coho, Pink, Chum, and Sockeye) as well as Steelhead Trout, resident Rainbow Trout, and Bull Trout. Operations at the Cheakamus generating station have the potential to alter the flow regime in the Squamish River downstream of where discharge from the plant enters the mainstem Squamish River. The objective of this report is to quantify potential effects of operations at CGS on the magnitude and pattern of flow in the mainstem Squamish River and evaluate the potential impact on salmonids.

The magnitude of the diversion of water from the Cheakamus River to the Squamish River has varied over time. An average of 74% of the annual inflow to the reservoir was diverted to the generating station between 1989 and 1995, well in excess of the 55% diversion rate specified in the original water license. The annual diversion rate decreased to 51% following implementation of the Instream Flow Agreement in 1996, and has averaged 53% since implementation of the WUP flows in 2006. The CGS has a maximum electrical capacity of 157 megawatts (MW), which represents 1.6% of the total capacity across all BC Hydro-owned generation systems (BC Hydro 2017). The maximum flow from the generating station is ~ 65 cubic meters per second (cms). Daisy Lake Reservoir can store a maximum of approximately 55 million cubic meters of water, which represents only 3.5% of the average annual inflow (BC Hydro 2005).

The CGS normally operates as a hydropeaking plant. Hydropeaking is a unique form of flow regulation that introduces short duration, high and low flow discharge patterns to meet short-term variation in electricity demand. Demand is higher during the day and lower at night. At many facilities, this results in high and steady flow releases during the day and low or no flow release during the night. When inflow to a generating station is limited, storing water at night when electrical demand is lower, and releasing water during the day when demand is higher, will result in an increase in hydroelectric revenues and better ability to meet peak electricity demand relative to running the plant at a steadier but lower flow for the entire 24-hour period. Hydropeaking operations at CGS typically occur during the winter when inflows to Daisy Lake are insufficient to run the plant at full capacity 24-hours per days. Plant shutdowns due to emergencies or scheduled maintenance activities can also result in rapid decreases in flow.

Rapid changes in flow from GCS have been shown to cause habitat loss, stranding, and direct mortality of fish in the connecting side channel and tailrace (Golder 2007, 2011, 2014a), but impacts of flow variation from CGS on fish populations in the mainstem Squamish River have not been evaluated. The contribution of flow from CGS to flow in the Squamish River will be greatest when natural flows in the Squamish River are low. Low flows in the Squamish River typically occur during winter months when most precipitation falls as snow and cool air temperatures limit snow and glacial melt. Discharge from CGS can be highly variable over this winter period due hydropeaking operations and has the potential to substantively influence the pattern of flow in the Squamish River, because natural inflows at this time are also low.

Effects of unnatural variation in flow on fish populations due to hydroelectric operations has been evaluated in a number of systems. Although there are still many unknowns, these studies have documented reduced macroinvertebrate production, stranding of redds and juvenile fish leading to higher mortality of eggs and early life stages, and chronic effects on metabolism and growth (see reviews by Bejarano et al. 2017, Moreira et al. 2018, Murchie et al. 2008). Korman and Campana (2009) demonstrated that the majority of Rainbow Trout fry in the Colorado River below Glen Canyon Dam did not move up and down the shoreline with the hourly change in flow over 24 hours to remain in shallow and low velocity habitat that small fry prefer. Instead most fry remained in deeper water during the high flow period of the hydropeaking cycle. This behaviour likely limited stranding, predation risk, and energy expenditure that would result from following the constantly moving immediate shoreline area over a 24-hour period. However, remaining in deeper and faster water likely increased energetic costs or reduced feeding efficiency, which lead to an observed decrease in growth (Fig. 2). This is one of the few studies that demonstrates that hydropeaking can have chronic effects by reducing habitat quality. A number of studies have documented direct mortality of hydropeaking resulting from stranding of incubating and juvenile life stages (McMichael et al. 2005, Connor and Pflug 2004, Harnish et al. 2014, Korman et al. 2011). This mortality is caused by fish spawning at higher elevations during peak flows which are then dewatered when flows are reduced to base levels.

Rearing or migrating fry also have the potential to be stranded by hydropeaking flows if they use high elevations that are wetted during the maximum flow of the hydropeaking cycle which are then dewatered when flows are reduced. Suitable habitat for recently emerged fry is limited to microhabitats with very shallow depth and low velocity (Armstrong and Nislow 2006). In larger systems like the Squamish River, these microhabitats are generally only found in the immediate shoreline areas (Nislow and Armstrong 2012) which are very sensitive to flow changes. Rapid changes in discharge and river stage can lead to stranding of fish as stage drops and lateral/downstream displacement as stage rises (Irvine et al. 2008, Young et al. 2011, Nagrodski et al. 2012, Gibeau et al. 2016). High flows can result in microhabitat velocities that exceed the limited swimming capacity for small post-emergent fry and can cause catastrophic displacement (Nislow and Armstrong 2012). Due to these factors a number of studies have shown that emergence and post-emergence periods are timed to coincide with periods that provide suitable flow conditions. For example, emergence is usually timed to occur before or after seasonal flooding, and year class failures of age-0 salmonids due to mistimed floods have been observed in a number of systems (see review in Nislow and Armstrong 2012). These studies indicate that hydrological alteration during the post-emergent fry stage can have negative effects on survival.

To minimize hydropeaking impacts on fish populations, maximum limits on the ratio of peak-to-base flows over 24-hour hydropeaking cycles have been proposed and are used by regulators in some cases. For example, the peak-to-base flow ratio in Austrian hydropeaking facilities is limited to 1.3-1.5 (see Moreira et al. 2018). Over longer time periods, minimizing differences in peak and base flows during spawning and incubation periods are used to reduce egg stranding in the Skagit River (Connor and Pflug 2004) and in the US (McMichael et al. 2005) and Canadian (Golder 2014b) portions of the Columbia River. Reductions in peak-to-base flows in the Colorado River in Glen Canyon from ~4 to ~2 resulted in a substantive increase in Rainbow Trout recruitment and abundance of a Rainbow Rrout population (McKinney et al. 2001, Korman et al. 2012). Restrictions in ramping rates have also been used in a number of systems to limit egg and fish stranding. Ramping rates have the potential to limit peak-to-base flow ratios if they are slow enough. In many systems, regulations specify both maximum ramping rates and maximum flow ranges within a day (peak-to-base flow ratios).

Restrictions on flow change at the Cheakamus Generating Station specified in the Cheakamus Water Use Plan (BC Hydro 2005) are very limited and are described in terms of changes in power production per unit time:

> *“During reduction of load at the Cheakamus powerplant between loads of 40 MW and 10 MW, the rate of reduction shall not exceed 10 MW every 5 minutes. Turbine ramping rates will be reviewed following the proposed Stranding Downstream of Generating Station study noted in Table 5-1.”*

Assuming this rules applies to the powerplant as opposed to each of its two turbines, 10 and 40 MW is equivalent to a powerplant discharge of ~7-16 cms, respectively. Within this range flows can vary by 9.7 cms/5 minutes which is equal to 116 cms/hr. Typically, the plant discharges changes from its peak capacity of 65 cms to 0 cms over a period of about 40 minutes (Colin Rombough, BC Hydro, pers. comm.). The study mentioned here involves measuring stage in the mainstem Squamish River near the confluence with the Ashlu Creek, and also describes evaluating stranding in the side channel immediately below the tailrace. Concerns about variation in flow from CGS on fish populations utilizing the mainstem Squamish River were therefore a concern during the original WUP and were raised again at the interim Cheakamus Water Use Plan (WUP) review meeting in 2012. In 2017, the Cheakamus WUP monitoring advisory committee recommended funding a desktop study to evaluate potential impacts of CGS operations on fish populations in the Squamish River during low flow periods. Owing to funding and time constraints, the scope of the study was limited to examining variation in river stage and discharge records in the mainstem Squamish River downstream of the confluence with the CGS connecting side channel. Potential impacts on fish populations would be inferred based on effects of CGS operations on flow and stage in conjunction with life history information that describes fish use of the mainstem Squamish River. This report summarizes the findings from this study.

2.0 Methods

The effect of variation in discharge from the Cheakamus generating station on patterns of flow in the Squamish River downstream of the generating station depends on the magnitude of flow in the Squamish River. This can be described by the equation, Squamish = Natural Inflow + CGS

where ‘Squamish’ refers to the discharge in the Squamish River at some location downstream of the generating station, ‘Natural Inflow’ is the discharge to the Squamish River from all natural inflow sources upstream of this location, and ‘CGS’ is the discharge from the powerhouse. When natural inflows are high relative to flows from the powerhouse, the effect of changes in flow from the powerhouse on discharge in the Squamish River will be small. In winter months, when natural inflow is often low, the effect of flow from CGS on the Squamish River will be greater.

My analysis relies on three long-term records of discharge. The hourly flow record at the Brackendale gauge on the Squamish River (WSC gauge 08GA022), located approximately 25 km downstream of CGS, shows the combined effect of CGS and natural inflows to flow in the mainstem Squamish River (Fig. 1b). This record, available from 1984 to 2017, represents the left side of the flow equation shown above. Patterns of natural inflow are characterized using the hourly record of discharge from the Elaho River at the mouth (WSC 08GA071). The Elaho River is much larger than the mainstem Squamish River at their confluence, and represents about 50% of the natural discharge in the Squamish River at the Brackendale gauge when averaged over the period of record (Fig. 3a). The Elaho record is assumed to provide a good characterization of the pattern of natural inflow to the Squamish River upstream of the Brackendale gauge. The hourly discharge record from CGS between 1984 and 2017 was provided by BC Hydro.

My analyses of these data were very simple. I began by plotting trends of the three discharge data series on the same graphs to visually determine the extent to which discharge from CGS influences the pattern and magnitude of flow in the Squamish River at the Brackendale gauge. As will be shown, these effects are very obvious during periods of low natural inflow to the Squamish River when discharge from CGS is variable over short time scales, and especially when CGS flows exhibit a hydropeaking signal.

To quantify the potential contribution of flows from CGS to flow in the Squamish River, I reconstructed the natural discharge at the Brackendale gauge. This reconstructed time series represents the natural flow regime at the Brackendale gauge in the absence of any inputs from CGS. I first computed the mean daily discharge at this gauge and at CGS from the hourly records, and then subtracted the mean daily CGS flow from the mean daily flow at the

Brackendale gauge. I calculated the fraction of time natural flows of 50, 100, 150, 200, and 250 cms at the Brackendale gauge on the Squamish River were exceeded. These exceedance frequencies were calculated for each month and using all months combined. I also calculated the ungauged natural flow contributing to flow at the Brackendale gauge by subtracting the mean daily flow from the Elaho River from the mean daily natural flow at the Brackendale gauge. The represents the natural local inflow between the confluence of the Elaho River and the Brackendale gauge.

The potential impact of a hydropeaking pattern in the Squamish River resulting from CGS operations was quantified by computing the ratio of maximum (peak) to minimum (base) flows within a day. Peak-to-Base flow ratios (P/B) were computed for each day with 24 hourly measurements of discharge at the Brackendale gauge on the Squamish River based on the following equation,

$$\frac{P}{B} = \frac{CGSmax + NatFlow}{NatFlow}$$

where CGSmax is the maximum discharge from CGS (65 cms) and NatFlow is the mean daily natural flow in the Squamish River at Brackendale. To quantify the natural level of within-day variation in flow, P/B was also computed using the discharge record from the Elaho River. In this case the numerator and denominator were maximum and minimum flows within each day, respectively. The percentage of days these ratios exceeded 1.3 or 1.5 (Moreira et al. 2018) was calculated for each year-month combination. Comparison of these P/B exceedance statistics from Squamish at Brackendale and Elaho time series were used to identify times of year and conditions when CGS is having a substantive impact on flow and stage in the mainstem Squamish River.

3.0 Results

3.1 Effects of CGS on Flow and Stage in the Squamish River

The Squamish River at Brackendale exhibits a typical seasonal pattern in discharge as determined by trends in precipitation and snowmelt (Fig. 3a). Flows are low during winter months when air temperatures are cool and most precipitation falls as snow, and flows are highest during spring and summer months when air temperatures are higher which results in snow and glacial melt leading to an increase in runoff. Discharge declines in late summer and early fall with the decrease in snowpack. The contribution of flows from CGS to flows at the Brackendale gauge on the Squamish River are modest when assessed using monthly averages. Average flow from CGS is lower during winter and higher during spring and summer and is largely determined by inflows to Daisy Lake. The Elaho River contributes about 50% of the total natural inflow at the Brackendale gauge on the Squamish River.

Flows from CGS exhibit a typical hydropeaking signal during periods when electricity demand is high and when inflows to Daisy Lake are low, which occurs in winter months. Data from the first week of March in 2017 provides an illustrative example (Fig. 4). Average inflow to Daisy Lake during this week was 16.1 cms. Over a typical day in this week, discharge from CGS was 0 cms from about midnight until 6 am, then rapidly rose to the current maximum plant discharge (~55 cms) by 8 a.m., remained at maximum discharge through early evening (~ 8 pm), and then declined rapidly to zero discharge and remained at this level until the next morning. This diurnal hydropeaking pattern is very evident in the Squamish River 25 km downstream of CGS at the Brackendale gauge. The morning rise in discharge from CGS is evident at the Brackendale gauge about three to four hours later. The pattern in the diurnal hydrograph at the Brackendale gauge is not quite as abrupt as it is from CGS owing to wave attenuation over the distance between CGS and the Brackendale gauge. The hydropeaking pattern at CGS and downstream at the Brackendale gauge also shows a more prolonged shutdown period on Sunday when electrical demand during the day is low compared to other days of the week. Such Sunday or weekend shutdowns are not uncommon (Fig. A1). Hydropeaking effects do not occur when the plant is operating at full capacity over a 24-hour period, which is common during late spring and most of the summer when inflows to Daisy Lake are high.

Owing to limited natural inflows in March 2017, peak discharge from CGS represented about ½ of the total discharge in the Squamish River at Brackendale (Fig. 4). As a result, flows over 24 hours at the Brackendale gauge ranged from a minimum of about 45 cms when CGS flows were zero, to about 90 cms when CGS was operating at full capacity, resulting in a P/B value of ~2. Such P/B values can result in substantive changes to stage. At the Brackendale gauge the flow change associated with a P/B value of two is 0.5 m (Fig. 5a) with maximum ramping rates of 12-15 cm/hr (Fig. 5b), which are well above the -2.5 cm/hr DFO guideline (FOC 2012).

CGS effects on flow and stage in the mainstem Squamish River are only evident in low flow months which typically occur from November though March (Fig. A1). P/B values decrease as natural inflows increase during spring and early summer (Table 1a). Average P/B values range between 1.7-1.9 during winter months (Fig. 3b). Daily P/B values greater than 1.3 or 1.5 are common in these months, especially when CGS is operating at full capacity. For example, in January 2000, 81% of days exceeded a P/B value of 1.5, compared to 0% of days based on the record for the Elaho River (Fig. A1). Averaged across years, P/B values in the Squamish River (Brackendale gauge) of 1.3 were exceeded between 61 to 68% of the time from November to March, while P/B values of 1.5 were exceeded 35 to 49% over the time (Table 2). These P/B criteria are exceeded due to natural levels of variation in flow in winter months, as shown by statistics from the Elaho system. However, during winter months, the exceedance probabilities for the CGS-influenced Squamish system are 1.6- to 4.1- fold higher than for the natural Elaho system for a P/B criterion of 1.3, and 1.6- to 6.9- fold higher for a P/B criterion of 1.5 (see SQ/EL ratios in Table 2). The opposite pattern occurs in summer months. Here the exceedance probabilities for P/B values of 1.3 in the Elaho system are considerably higher than the CGS-influenced Squamish system due diel variation in snowmelt. Exceedance probabilities for a P/B criterion of 1.5 are generally low in both the Squamish and Elaho systems in summer.

Operating rules at Daisy Lake Dam also effect patterns of release from CGS during winter. For example, under the Instream Flow Agreement (IFA), which was in place from 1996-2006, 37-52% of the previous week’s inflow was required to be released from Daisy Dam into the Cheakamus River. At CGS, this resulted in periods of hydropeaking followed by multi-day shutdowns to ensure that the weekly release to the Cheakamus was sufficient to meet the 37-52% inflow requirement (e.g., Feb and Mar 2001, Fig. A1).

Short-term variation in discharge in the Squamish River resulting from CGS operations in low flow winter months has the potential to result in significant loss of habitat for rearing juvenile salmonids or stranding of juveniles. The majority of habitat in the Squamish River downstream of the confluence of the side channel that CGS flows into is relatively low angle and highly braided (Fig. 6). Large areas of gravel bar would be exposed as flows change from peak to base levels over the 24-hour hydropeaking cycle during low flow winter months. Some braided channels could be dewatered between peak and base flow levels.

There can be considerable natural within-day variation in discharge in the Squamish River resulting from glacial melt in the late summer. Within-day cycles in flow in the Elaho and Squamish River at Brackendale gauges are evident from June through September, with the strongest cycles typically occurring in August and September (Fig. A1, Table 2). The intensity of this natural variation is minimal in some years (e.g. 1997) but much higher in others (e.g. 2016). Natural diurnal variation in summer discharge is likely higher during periods of very warm weather causing increased melting of snow and ice. Owing to the travel time between the area where snow and ice melts and the location of the Brackendale gauge, discharge at the Brackendale gauge actually rises during the night and peaks in early morning before falling over the course of the day (Fig. 7). Absolute differences between peak and base flows at the Brackendale gauge caused by natural within-day variation in summer are higher than CGS-caused within-day variation in low flow winter months. However, owing to much higher flows during summer, the natural maximum P/B ratio in summer at the Brackendale gauge (~475/400 = 1.1) are considerably lower than CGS-driven values in winter (~90/45 = 2).

3.2 Potential Effects of CGS Flows on Fish Populations in the Squamish Watershed

3.2.1 Life History

Effects of short-term variation in flow in the Squamish River resulting from operations at CGS on fish populations that utilize the Squamish River will depend on the time of year various life stages are present in the mainstem. These patterns have been summarized by Golder (2005) and are reviewed here with a focus on the November to March period when CGS effects on discharge in the mainstem Squamish River are greatest.

Pink Salmon

Pink Salmon spawn throughout the mainstem of the Squamish River and in many of its tributaries from August through October. Redd stranding in the mainstem Squamish due to CGS operations is unlikely as differences in flow between spawning and emergence are largely driven by natural variation in inflow. Pink fry migrate during March and April and fry migrating in March could potentially be susceptible to stranding and habitat loss driven by CGS operations. Newly emerged fry using immediate shoreline areas prior to migrating would also be vulnerable to CGS-driven variation in flow and stage.

Chum Salmon

Chum Salmon spawn in the mainstem of the Squamish River and its tributaries from October through January. Redds excavated in the mainstem Squamish after October during peak CGS flow and when natural inflows are low, could potentially be dewatered when CGS flow is reduced. Outmigration of chum fry occurs between March and May. Newly emerged fry and migrating fry in March would be susceptible to habitat loss and stranding from CGS operations.

Chinook Salmon

Chinook Salmon spawn in the mainstem Squamish River and its tributaries in July and August. Chinook fry rear along the margins in side channels of the larger tributaries and the mainstem Squamish River. If patterns of outmigration follow those in the Cheakamus River, fry outmigrate in February, March, and April, with peak outmigration typically occurring in February and early March (Melville and McCubbing 2012). The majority of outmigrating fry in the Squamish system would therefore be susceptible to stranding and habitat loss from CGS operations. Chinook juveniles that do not migrate in the winter and spring following emergence would reside in the Squamish mainstem and its tributaries over the summer and the next winter before migrating as yearlings the following spring. Chinook juveniles typically move from tributaries into a larger mainstem with the approach of winter (see review in Healy 1991, Bradford and Taylor 1997). This behaviour likely occurs in the Squamish watershed and would result in the exposure of Chinook parr to winter fluctuations in flow driven by CGS hydropeaking operations. As described below there are a variety of mechanisms by which these fluctuations could reduce growth and survival rates.

Coho Salmon

Coho Salmon spawn in the mainstem Squamish River, Ashlu Creek, and a variety of smaller tributaries. Spawning occurs from November through January and fry emerge from March through June and spend an additional year in freshwater before migrating the following spring in April and May. In the Thompson system, Coho Salmon fry and parr that originated from smaller tributaries make extensive use of the Thompson River mainstem during winter prior to outmigrating as smolts (Shrimpton et al. 2014). A similar pattern of habitat use likely occurs in the mainstem Squamish River. These overwintering Coho Salmon would be exposed to winter fluctuations in flow driven by CGS operations.

Sockeye Salmon

There may still be a small population of stream-type Sockeye Salmon in the Squamish system that largely uses Ashlu Creek, but is uncertain whether this population still exists. These fish would spawn in August and September. As emerging fry do not have access to a lake, they likely behave like other stream-type Sockeye populations and migrate downstream as fry to an estuary or remain in freshwater and rear in spring areas, side channels, and sloughs. If sockeye juveniles utilize the mainstem Squamish River for an extended period prior to migrating to the estuary, they would be exposed to winter fluctuations in flow driven by CGS operations.

Steelhead Trout

Steelhead Trout spawn in the mainstem Squamish River and a variety of tributaries. Spawning occurs from April through June and fry would emerge in the summer. These life stages are likely not susceptible to CGS operations at is has little effect on flows in the mainstem Squamish at this time of year. However, juvenile Steelhead Trout likely overwinter in the Squamish mainstem as they do in the Thompson system (Decker et al. 2015). These overwintering fish would be exposed to CGS-driven fluctuations in flow for a minimum of two years prior to leaving as two- and three-year old smolts in the spring.

Resident Rainbow Trout and Bull Trout

Resident rainbow trout and Bull trout are found in the Squamish system. Little is known about their distribution though Bull Trout are suspected to spawn near the Elaho River confluence. These resident species would spend the majority of their life in the mainstem Squamish River and are potentially susceptible to CGS-driven fluctuations in flow during winter.

3.2.2 Mechanisms of Impact

There are a variety of ways that CGS-driven variation in flow and stage in the mainstem Squamish River could impact salmonid populations.

Redd Stranding

Redds from chum salmon spawning in the mainstem Squamish in November and later months when natural inflows are low could be vulnerable to dewatering. This would occur if spawning occurred during a period of low natural inflows but when the plant was operating at full capacity. If this occurs, redds excavated in shallow water would be exposed when discharge from CGS is reduced. Eggs and alevins in redds may survive brief periods of dewatering but may freeze and die when air temperatures are cold. Alevins are much more sensitive to variation in temperature and dewatering than hardened egg stages, so impacts to all species that emerge in late winter (Chinook, Pink, Chum) are possible. This impact seems likely, but the extent is unknown.

Stranding and Reduced Habitat Quality and Availability for Fry

Many Chinook, Chum, and Pink salmon fry migrate in March when CGS-driven flow variation in the mainstem Squamish can be large. Fry typically migrate at night and hide in or very close to the substrate in shallow shoreline areas during the day (Groot and Margolis 1991, Melville and McCubbing 2012). In the Cheakamus River, Chinook fry are very abundant in the immediate shoreline area during electrofishing surveys for Steelhead Trout in late March and early April (see Korman and Schick 2017 for details of sampling). There are a variety of ways that fry are potentially harmed by fluctuating flows. Flows at the Brackendale gauge drop over the majority of the nighttime period when fry would be migrating. This could result in stranding of fish that are near the river margins or in braids. Fry that are not migrating and instead holding in shoreline areas at peak flow elevations would be vulnerable to stranding. Those holding over substrate in deeper water to avoid moving up and down the shoreline with the hydropeaking cycle (as in Korman and Campana 2009) could have lower growth rates or be exposed to greater predation risk (Fig. 2). Some habitats that would be available to fry in the mainstem Squamish under natural flows, may be completely unusable due to CGS operations that cause large variation in velocity and depth over the hydropeaking cycle.

Standing and Reduced Habitat for Parr

It is highly likely that Chinook, Coho, Steelhead and resident Rainbow Trout, and Bull Trout parr overwinter in the mainstem Squamish River. Parr are larger than fry and tend to use deeper water and would therefore be less vulnerable to stranding. It is more likely that CGS-driven diurnal variation in flow during winter reduces the amount or quality of habitat parr can use. Salmonid parr are concealed in the substrate in winter months due to cold water temperatures and only leave the substrate at night (Bradford and Higgins 2001). Steelhead Trout and Coho Salmon parr in the Cheakamus River have been enumerated using nighttime snorkel surveys since 2008 (Korman and Schick 2017). These fish are commonly seen holding close to the river bed and bank in low velocity conditions (Korman et al. 2010), likely to reduce energy expenditure. Parr are virtually absent in the deeper parts of the channel where velocities are higher. Discharge in the mainstem Squamish River downstream of CGS is high during the day and drops from peak to minimum values during the night (Fig. 4). In shallow cobble bar areas, which are very common in the mainstem Squamish (Fig. 6), parr would have to move up into higher elevation habitats at the start of the evening when flows are high to find low velocity habitat, and then move to lower elevations as the flow drops. There would likely be energy and predation costs associated with this movement. Alternatively, parr may restrict habitat use to locations that function over the full range of diurnal discharges (e.g. eddies and pools) so that they can avoid diel movement. This would limit the amount of useable habitat, and there may be greater energetic costs or predation risks associated with using these types of environments.

Reconciling Effects of Natural Within-Day Variation in Flow during Summer

The analysis of flow data shows that there can be natural variation in flows over a day in summer months due to patterns of snowmelt, especially in the Elaho River. Summertime exceedance probabilities for P/B values greater than 1.5 are high in the Elaho River but low in the lower Squamish River (Brackendale gauge). In order to rationalize a change in CGS operations to reduce the frequency of high P/B values in the Squamish River during winter, one needs to assume that either the effects of high P/B values on fish in winter are greater than in summer, or that there is greater fish use in the lower mainstem Squamish River than in the Elaho River. The latter assumption seems likely given that the majority of fish bearing tributaries are located well downstream of the confluence with the Elaho River. Energetic costs for parr associated with movement/selection of non-optimal habitat resulting from hydropeaking could be higher in winter as water temperatures are too cold for fish to compensate for energy losses. Owing to patterns in emergence and fry migration there is little doubt that vulnerable life stages make greater use of the Squamish mainstem during part of the winter (February and March) compared to summer months.

4.0 Uncertainty in Biological Effects of Hydropeaking in the Squamish River

The potential response of fish populations that utilize the Squamish River to reduced hydropeaking at CGS is uncertain. There are a number of studies that show that reductions in hydropeaking can produce tangible benefits for fish populations (see Bejarano et al. 2017. Moreira et al. 2018, Murchie et al. 2008). However, there is wide variation in both the magnitude of response, and the types of systems that were studied, so it is not possible to use this information to make quantitative predictions about benefits that might occur in the Squamish system. A logical alternative is to use an Adaptive Management approach to monitor the response of redd stranding and juvenile survival, growth, and abundance with and without restrictions on CGS operations. However, quantifying these metrics for fish populations using the mainstem Squamish River would be very challenging. Surveys for stranded Chum redds could be conducted with some effort, but assessing the population level impact would require an understanding of the proportion of the total number of redds in the system that are stranded. This is a daunting task given the size of the Squamish River and its many tributaries. Juvenile fish densities in the Squamish mainstem are low owing to its large size and relatively depleted fish populations (Van Dischoeck 2000). Thus, a very large number of juvenile sampling sites will be required to quantify densities in years with and without hydropeaking restrictions (Korman et al. 2012). Many years of study would be required to account for interannual variation in abundance driven by factors other than CGS operations. Surveys for stranded fish could provide a qualitative measure of effects, but stranding metrics will vary with abundance prior to stranding events which would be challenging to quantify. Owing to this issue and many others, stranding surveys will therefore provide only a very course assessment of potential benefits of reduced hydropeaking. In addition, hydropeaking has been shown to result in chronic impacts that are unrelated to stranding (e.g. Korman and Campana 2009), so quantifying changes in stranding will not capture all the potential benefits associated with reduced hydropeaking.

Quantifying effects of CGS hydropeaking on habitat in the mainstem Squamish downstream of the plant would be feasible. Air photographs of the effected area show a highly braided channel that is potentially sensitive to variation in flow (Fig. 6). Ground surveys could quantify the area of gravel bars and braids that are dewatered between peak and base CGS flows at a limited number of sites. Other metrics, such as the change in velocity and depth between base and peak CGS flows could be used to quantify potential impacts of hydropeaking on habitat quality. Although these statistics can’t be used to make reliable predictions on effects of hydropeaking on fish populations, they are at least feasible to collect. And if these statistics show that exposed areas and depth/velocity differences between peak and base flows are very small, our qualitative prediction of hydropeaking impacts on fish populations would be less, which could be useful information for decision-makers.

This report provides information that contributes to a first step in the decision on whether to constrain operations at CGS to limit flow variation in the mainstem Squamish River. CGS-driven variation in flow can be substantive during low inflow periods in November through March and often exceeds literature-supported thresholds considered to be harmful for fish.

5.0 References

Armstrong, J.D. and K.H. Nislow. 2006. Critical habitat during the transition from maternal provisioning in freshwater fish, with emphasis on Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Journal of Zoology 269:403-413.

BC Hydro. 2017. BC Hydro quick facts. Available at: https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/accountability-reports/financial-reports/annual-reports/bchydro-quick-facts-june-2017.pdf

BC Hydro. 2005. Cheakamus Project Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. A BC Hydro Water Use Plan 1 October 2005.

Bejarano, M.D., Sordo-Ward, A., Alonso, C., and C. Nilsson. 2017. Characterizing effects of hydropower plants on sub-daily flow regimes. Journal of Hydrology 550:186-200.

Bradford, M.J., and P.S. Higgins. 2001. Habitat-, season- and size-specific variation in diel activity patterns of juvenile Chinook salmon (*Oncorhynchus tschawytscha*) and steelhead trout (Oncorhynchus mykiss). Canadian Journal of Fisheries and Aquatic Sciences 58:365-374.

Bradford, M. J., and G. C. Taylor. 1997. Individual variation in dispersal behaviour of newly emerged Chinook salmon (*Oncorhynchus tschawytscha*) from the Upper Fraser River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 54:1585-1592.

Connor, E.J., and D.E. Pflug. 2004. Changes in the distribution and density of pink, chum, and Chinook salmon spawning in the upper Skagit River in response to flow management measures. North American Journal of Fisheries Management 24:835-852.

Decker, A.S., Hagen, J., and R.G. Bison. 2015. Stock productivity, carrying capacity, and habitat utilization of Thompson River steelhead, as estimated from 2001-2012 juvenile abundance data. Report prepared for Habitat Conservation Trust Fund, 67 p.

Fisheries and Oceans Canada (FOC). 2012. Review of long-term monitoring protocols for new and upgraded hydroelectric projects in British Columbia and Yukon Territory. Canadian Science Advisory Secretariat proceedings series 2012/045. 23 pp.

Gibeau, P., Connors, B., and W. Palen. 2017. Run-of-river hydropower and salmonids: potential effects and perspective on future research. Canadian Journal of Fisheries and Aquatic Sciences 74: 1135-1149.

Golder. 2014a. Monitoring stranding downstream of Cheakamus generating station, implementation year 4. CMSMON-4. Report prepared for BC Hydro by Golder Associates.

Golder. 2014b. Lower Columbia River: Whitefish life history and egg mat monitoring program: Year 5 interpretive report. CLBMON-48. Report prepared for BC Hydro by Golder Associates.

Golder. 2011. Monitoring stranding downstream of Cheakamus generating station, summary of year 1 and 2. CMSMON-4. Report prepared for BC Hydro by Squamish Nation and Golder Associates.

Golder. 2009. Monitoring stranding downstream of Cheakamus generating station, implementation (year 1). CMSMON-4. Report prepared for BC Hydro by Squamish Nation and Golder Associates.

Golder. 2005. Squamish River watershed salmon recovery plan. Report prepared for the Pacific Salmon Foundation by Golder Associates.

Groot, C., and L. Margolis. 1991. Pacific Salmon Life Histories. UBC Press, Vancouver. 564 pp.

Harnish, R.A., Sharma, R., McMichael, G.A., Langshaw, R.B., Pearsons, T.N., and R. Hilborn. 2014. Effect of hydroelectric dam operations on the freshwater productivity of a Columbia River fall Chinook salmon population. Canadian Journal of Fisheries and Aquatic Sciences 71:602-615.

Healy, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tschawytscha*). In Pacific Salmon Life Histories, C. Groot and L. Margolis [eds]. UBC Press, Vancouver.

Irvine R.L., Oussoren T., Baxter J.S., and D.C. Schmidt. 2009. The effects of flow reductions on fish stranding in British Columbia, Canada. River Research and Applications 25: 405-415.

Korman, J. and J. Schick. 2017. Cheakamus River steelhead juvenile and adult abundance monitoring (year 10). Report prepared for BC Hydro.

Korman, J., Schick, J., and B. Mossop. 2012. Estimating river-wide abundance of juvenile fish populations: How much sampling is enough? North American Journal of Fisheries Management 36:213-229.

Korman, J., Martell, S.J.D., Walters, C.J., Makinster, A.S., Coggins, L.G., Yard, M.D., and W.R. Persons. 2012. Estimating recruitment dynamics and movement of rainbow trout (*Oncorhynchus mykiss*) in the Colorado River in Grand Canyon using an integrated assessment model. Canadian Journal of Fisheries and Aquatic Sciences 69: 1827-1849.

Korman, J., Kaplinski, M., and T.S. Melis. 2011. Effects of fluctuating flows and a controlled flood on incubation success and early survival rates and growth of age-0 rainbow trout in a large regulated river. Transactions of the American Fisheries Society. 140: 487-505.

Korman, J., Decker, A.S., Mossop, B., and J. Hagen. 2010. Comparison of electrofishing and snorkeling mark-recapture estimation of detection probability and abundance of juvenile steelhead in a medium-sized river. North American Journal of Fisheries Management 30:1280-1302.

Korman, J., and S.E. Campana. 2009. Effects of hydropeaking on nearshore habitat use and growth of age-0 rainbow trout in a large regulated river. Transactions of the American Fisheries Society: 138:76-87.

McKinney, T., Speas, D.W., Rogers, R.S., and W.R. Persons, 2001. Rainbow trout in a regulated river below Glen Canyon Dam, Arizona, following increased minimum flows and reduced discharge variability. North American Journal of Fisheries Management 21:216–222.

McMichael, G.A., McKinstry, C.A., Vucelick, J.A., and J.A. Lukas. 2005. Fall Chinook salmon spawning activity versus daylight and flow in the tailrace of a large hydroelectric dam. North American Journal of Fisheries Management 25:573-580.

Melville, C.C. and D.J. McCubbing. 2012. Juvenile salmonid outmigration enumeration assessment summary report 2001-2011. Report prepared by Instream Fisheries Research Inc. for BC Hydro.

Moreira, M., Hayes, D.S., Boavida, I., Schletterer, M., Schmutz, S., and A. Pinheiro. 2018. Ecologically-based criteria for hydropeaking mitigation: A review. Science of the Total Environment 657:1508-1522.

Murchie, K.J., Hair, K.P., Pullen, C.E., Redpath, T.D., Stephens, H.R., Cooke, S.J., 2008. Fish response to modified flow regimes in regulated rivers: research methods, effects and opportunities. River Research and Applications 24:197–217.

Nagrodski A., Raby G.D., Hasler C.T., Taylor M.K., and S.J. Cooke. 2012. Fish stranding in freshwater systems: sources, consequences, and mitigation. Journal of Environmental Management 103:133-141.

Nislow, K.H., and J.D. Armstrong. 2012. Towards a life-history-based management framework for the effects of flow on juvenile salmonids in stream and rivers. Fisheries Management and Ecology 19:451-463.

Niu, S. and M. Insley. 2013. Balancing profitability and environmental costs. Energy Economics 39:39-52.

Shrimpton, J.M., Warren, K.D., Todd, N.L., McRae, C.J., Glova, G.J., Telmer, K.H., and A.D. Clarke. 2014. Freshwater movement patterns by juvenile Pacific salmon *Oncorhynchus* spp. Before they migrate to the ocean: Oh the places you'll go! Journal of Fish Biology 85:987-1004.

Van Dischoeck, P. 2000. Squamish River system juvenile steelhead sampling program. Report prepared for BC Ministry of Environment, Lands, and Parks by Aquatic Resources Limited.

Young P.S., Cech Jr., J.J., and Thompson L.C. 2011. Hydropower-related pulsed-flow impacts on stream fishes: a brief review, conceptual model, knowledge gaps, and research needs. Reviews in Fisheries Biology and Fisheries 21:713-731.

Table 1. Peak-to-base flow ratios at the Brackendale gauge on the Squamish River based on peak flows at the Cheakamus Generating Station (CGS) of 65 cms and natural base flows in the Squamish River ranging from 50 to 250 cubic meters per second (cms, a)), and exceedance probabilities by month based on natural flows at the Brackendale gauge on the Squamish River (b).

a) Peak to Base Flow Ratio

	Natural Squamish Flow @ Brackendale (cms)				
	50	**100**	**150**	**200**	**250**
	2.30	1.65	1.43	1.32	1.26

b) **Exceedance Probability (%)**

	Unimpaired Squamish Flow @ Brackendale (cms)				
Month	**50**	**100**	**150**	**200**	**250**
Nov	86	49	29	18	14
Dec	62	19	8	5	3
Jan	57	20	10	6	4
Feb	54	14	6	3	2
Mar	67	22	7	4	2
Apr	89	53	24	13	6
May	92	87	73	60	45
Jun	95	95	95	92	85
Jul	94	94	94	94	92
Aug	94	94	94	91	76
Sep	96	89	70	45	25
Oct	94	62	38	26	17
All Months	82	58	46	38	31

Table 2. Frequency (%) of days in a month where the daily peak-to-base ratio is greater than or equal to 1.3 and 1.5 for the Squamish River at the Brackendale gauge (SQ) and at the mouth of the Elaho River (EL). 'SQ/EL' shows the ratio of frequencies. Average monthly values are based on all data from 1984-2017 where there were at least 10 days where peak-to-base values could be computed for both Squamish and Elaho locations.

	Peak-to-Base Ratio					
	1.3			**1.5**		
Month	**SQ**	**EL**	**SQ/EL**	**SQ**	**EL**	**SQ/EL**
Nov	68	43	1.6	45	27	1.6
Dec	66	25	2.7	49	12	4.2
Jan	66	30	2.2	45	16	2.9
Feb	62	15	4.1	41	6	6.9
Mar	61	21	2.9	35	10	3.5
Apr	46	29	1.6	20	11	1.7
May	36	55	0.7	10	18	0.6
Jun	22	65	0.3	6	14	0.4
Jul	17	68	0.2	3	9	0.3
Aug	32	79	0.4	7	33	0.2
Sep	49	86	0.6	18	46	0.4
Oct	63	64	1.0	36	34	1.0

a) Map of the Cheakamus-Squamish systems and locaton of hydroelectric facilities (from BC Hydro 2005)

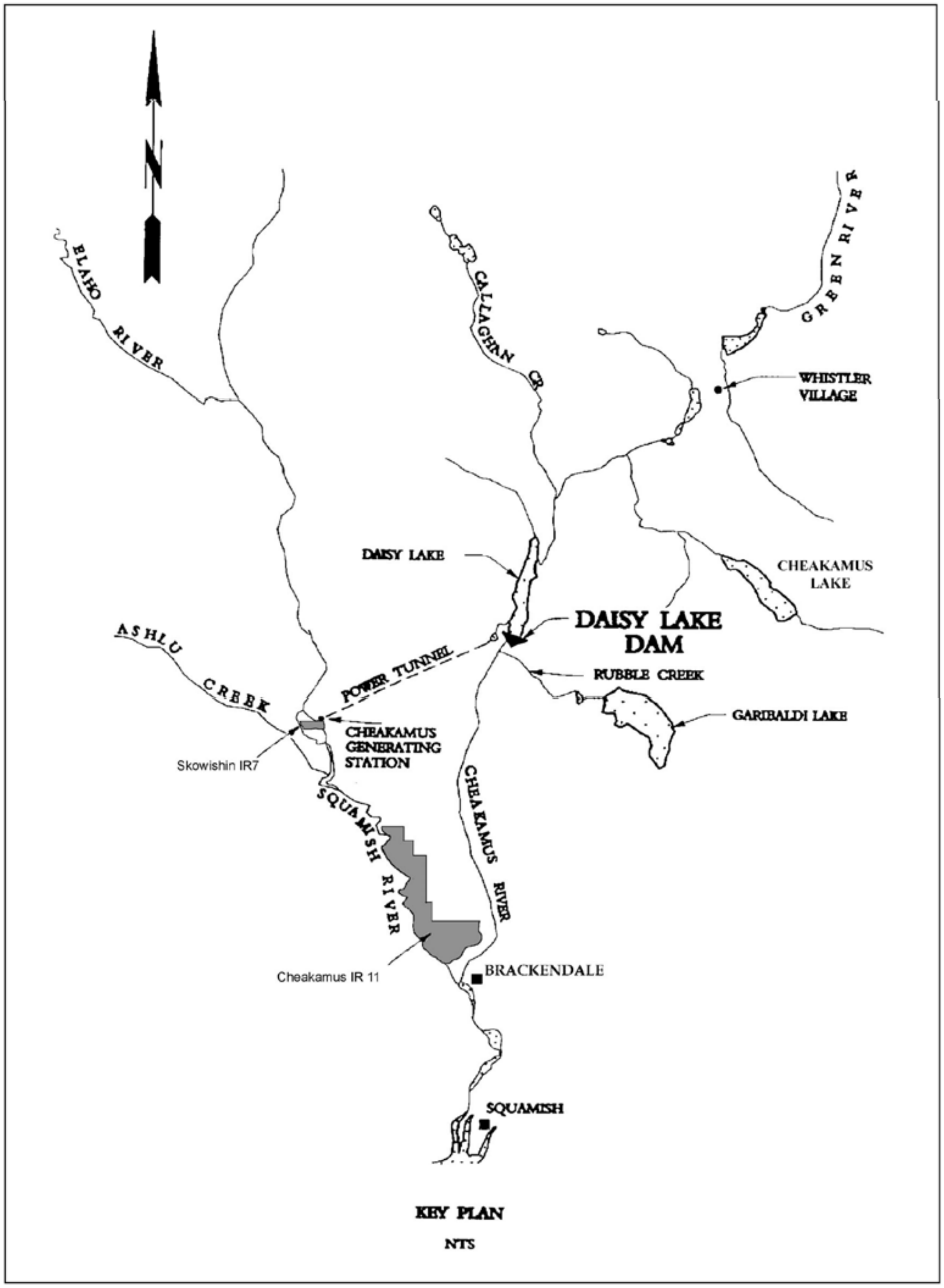


Figure 1. Map of the Squamish and Cheakamus River systems and BC Hydro electrical facilities (a) and Google earth image showing the locations of the gauging stations on the Elaho (at mouth) and Squamish Rivers (at Brackendale), the Cheakamus generating station discharging water from Daisy Lake into the Squamish River, and the Daisy Lake Dam on the Cheakamus River (b). The Brackendale gauge is located ~ 25 km downstream of the generating station.

b) Google earth image of Squamish and Cheakamus Rivers

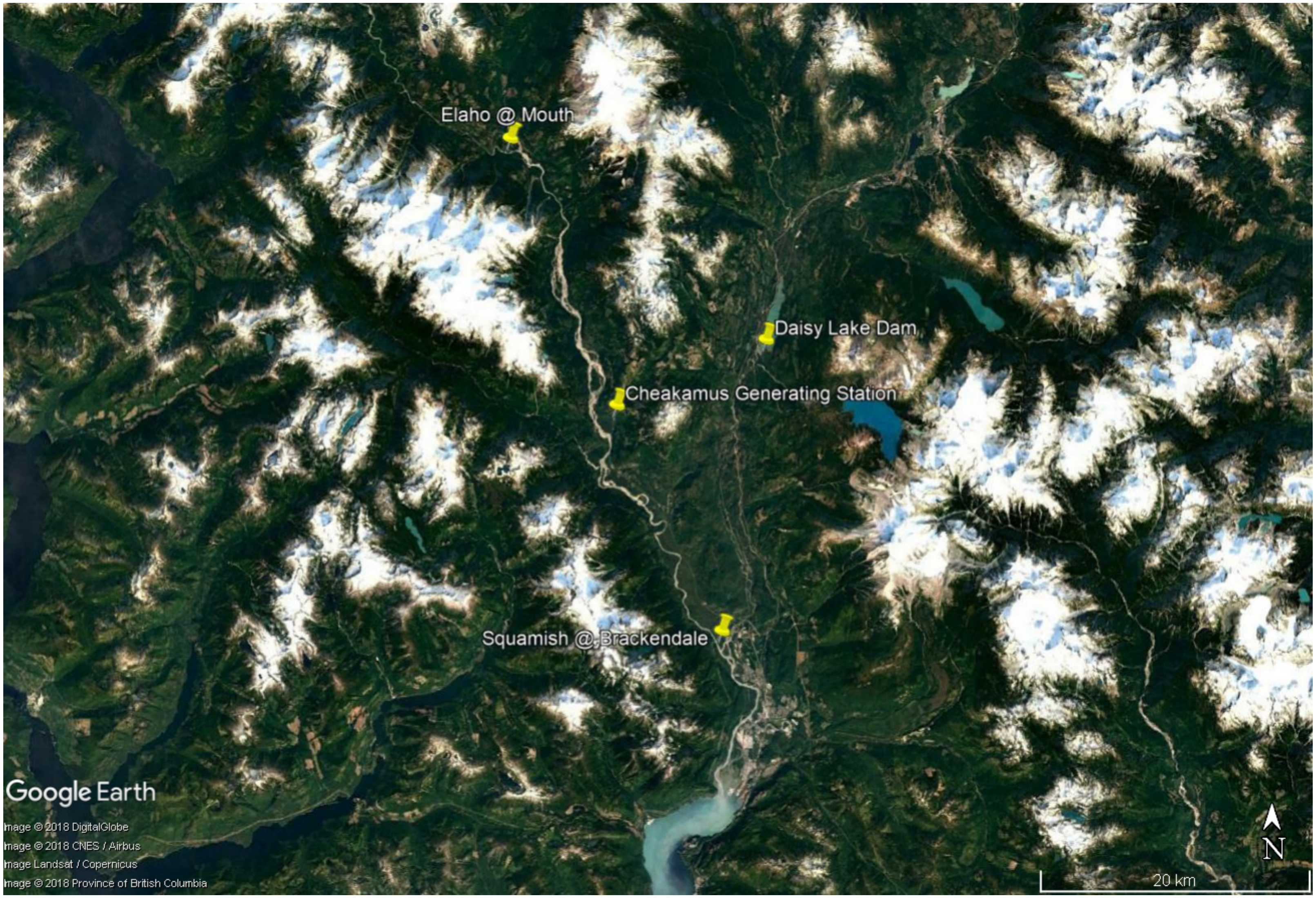


Figure 1. Con't.

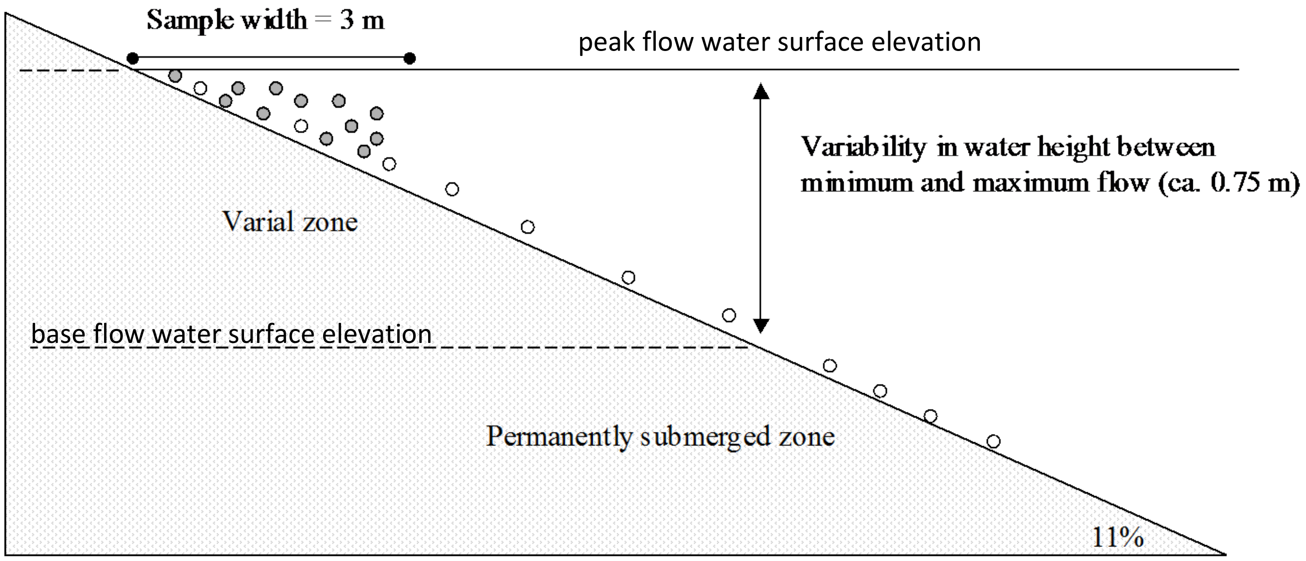


Figure 2. Depiction of a cross-section of shoreline habitat at the maximum and minimum discharge over a 24h-hour period in the Colorado River below Glen Canyon Dam. Shaded circles represent the hypothesized distribution of age-0 trout during the daily maximum flow on weekdays under the shoreline-tracking hypothesis. Open circles represent the distribution under the restricted-movement hypothesis, where only a small proportion of individuals remain in the immediate nearshore zone close to the waters edge. Reproduced from Korman and Campana (2009).

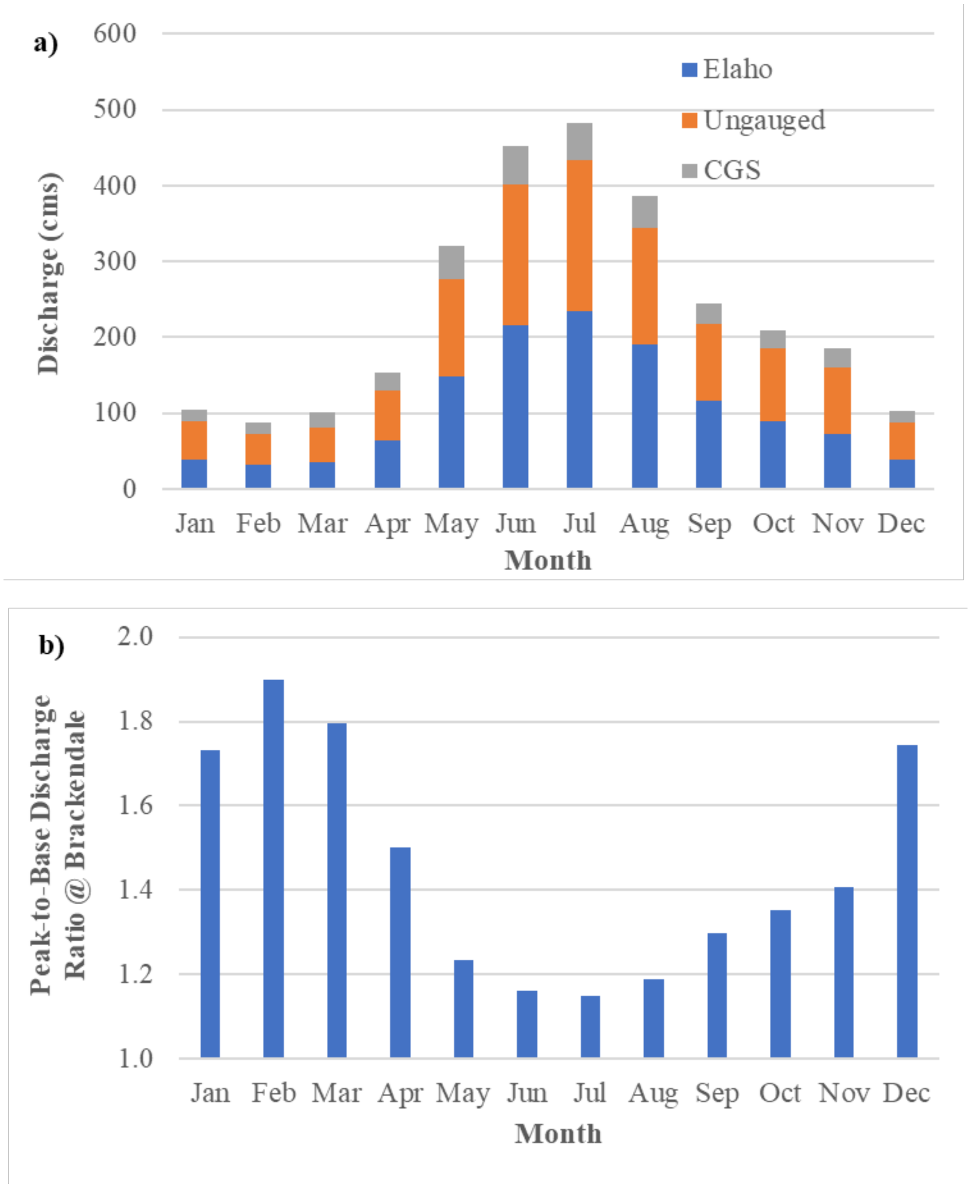


Figure 3. Average discharge over the period of record (1984-2017) by month in the Elaho and Squamish Rivers (Brackendale gauge) and from the Cheakamus Generating Station (CGS, a), and the ratio of peak-to-base discharge at the Brackendale gauge in Squamish (b). In a) the ungauged discharge was computed as the difference between the natural flow at the Brackendale gauge and the Elaho River flow. The total height of the bars represents the discharge at the Brackendale gauge and the combined height of blue and orange bars represents the natural flow at the Brackendale gauge. In b), the peak-to-base flow ratio is computed as the sum of the maximum CGS discharge (65 cms) and average natural flow in the Squamish River at the Brackendale gauge divided by the average natural flow at the Brackendale gauge.

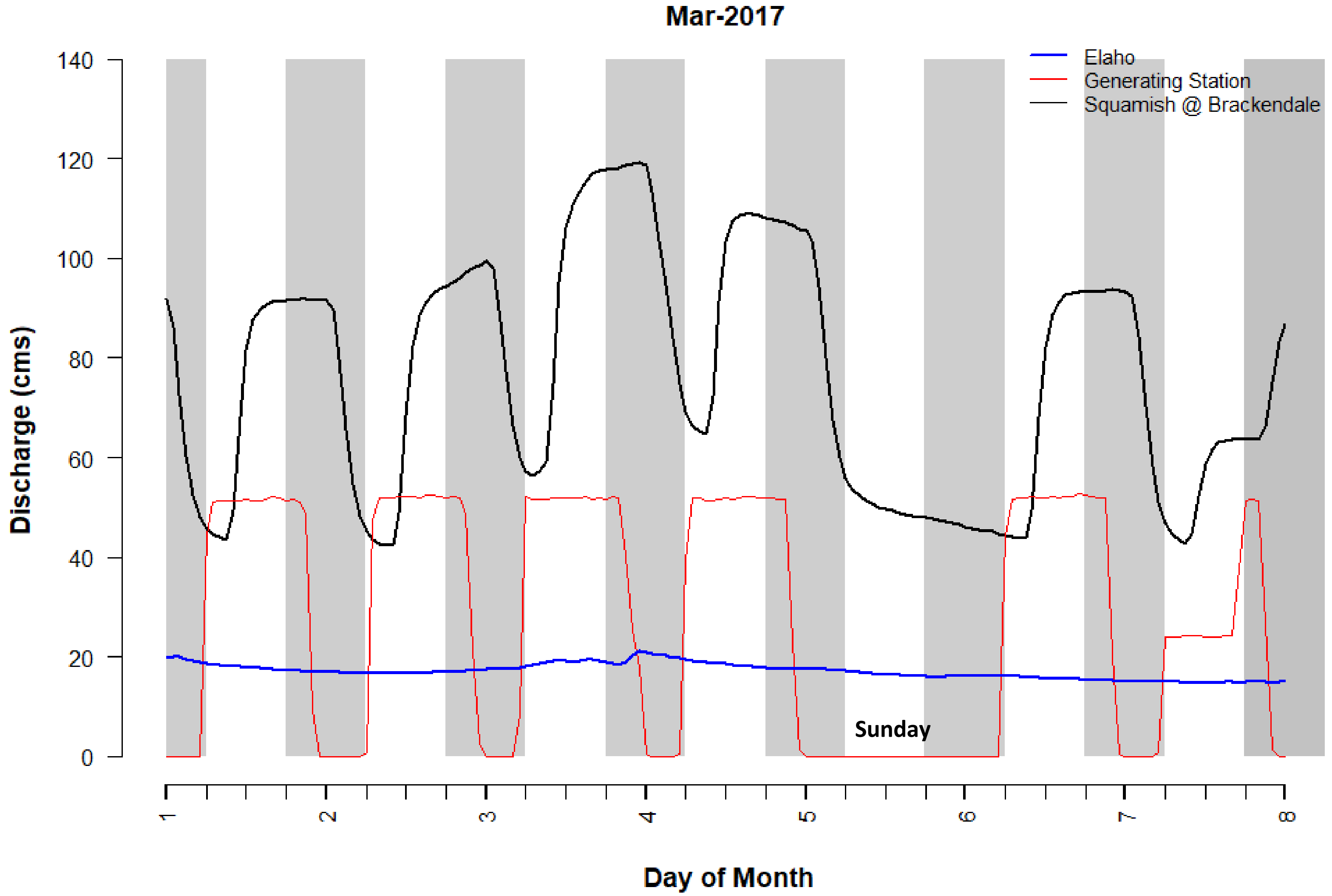


Figure 4. Detail of effect of the Cheakamus generating station discharge (red line) on flows in the Squamish River at Brackendale (black line) in the first week of March, 2017. Elaho River discharge (blue line) shows the pattern of natural inflows upstream of the Brackendale gauge. Grey rectangles identify nighttime periods (sunset to sunrise).

a) Stage

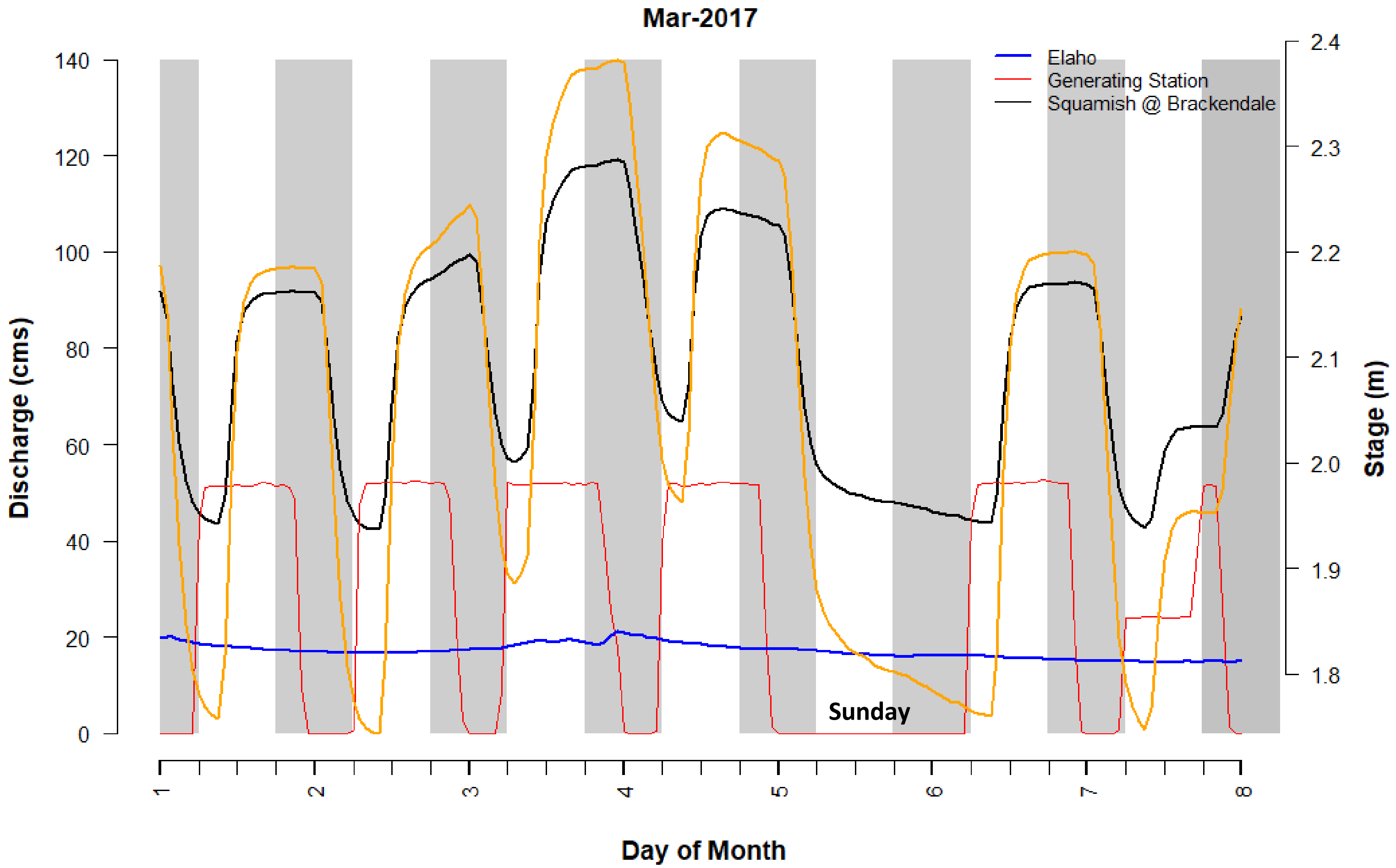


Figure 5. Detail of effect of the Cheakamus generating station discharge on flows in the Squamish River at Brackendale in the first week of March, 2017 showing stage (a) and rate of stage change (b) at the Brackendale gauge on the Squamish River (orange line), and discharge at this gauge (black line) and from CGS (red line) and the Elaho River (blue line). Grey rectangles identify nighttime periods (sunset to sunrise).

b) **Rate of stage change**

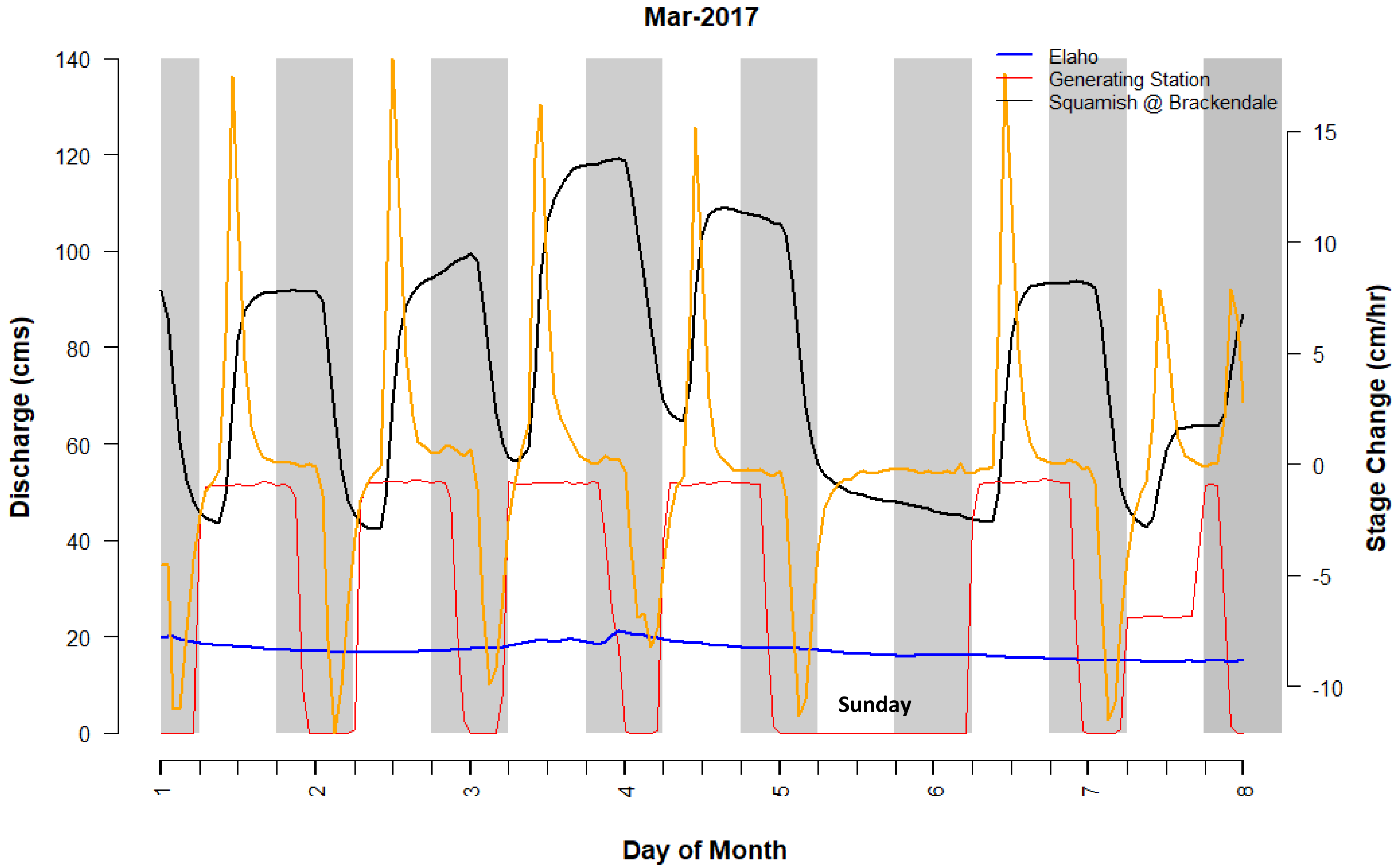


Figure 5. Con’t.

Figure 6. Google earth image showing a detail of the very braided section of the Squamish River near and downstream of the Ashlu Creek confluence.

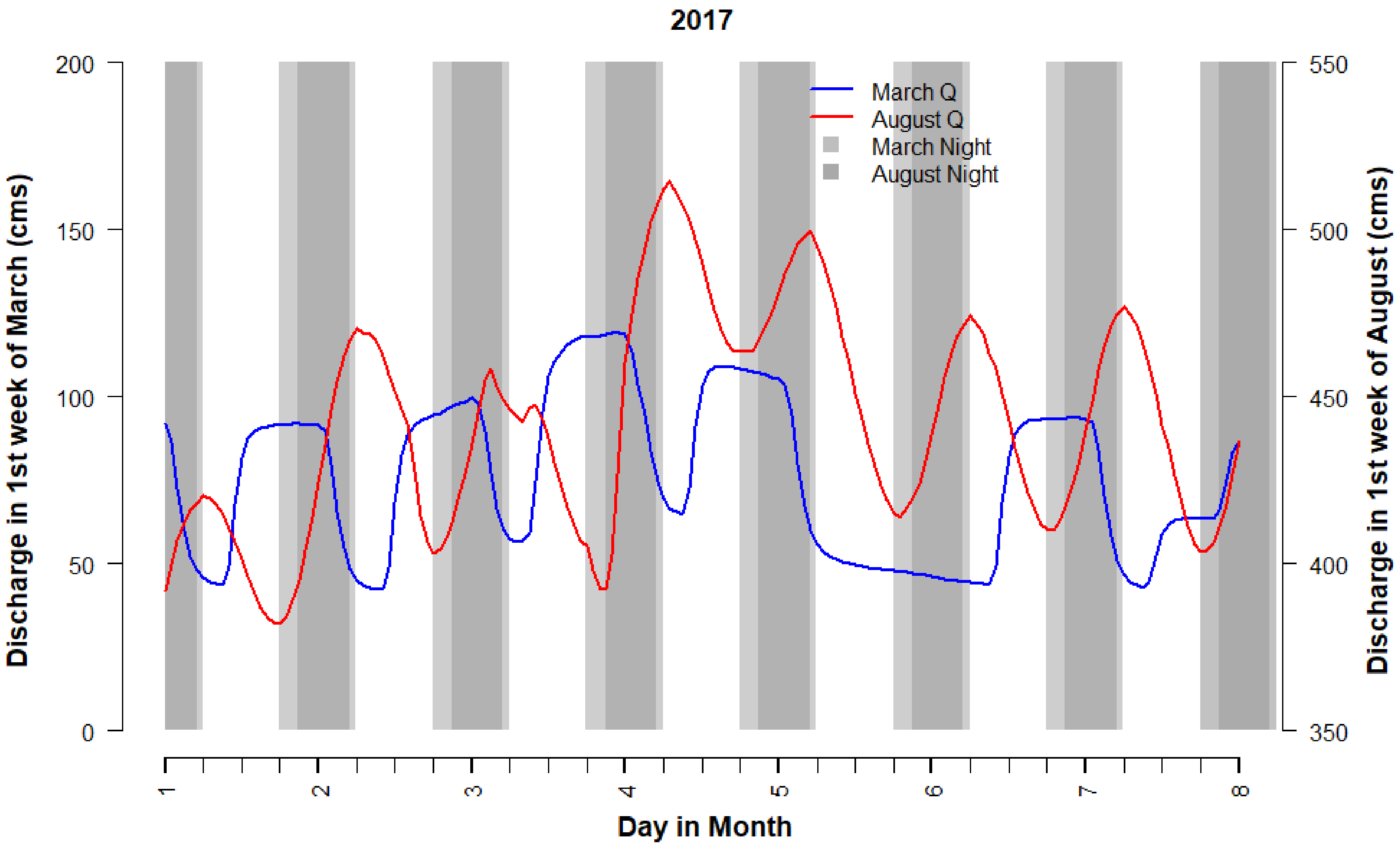
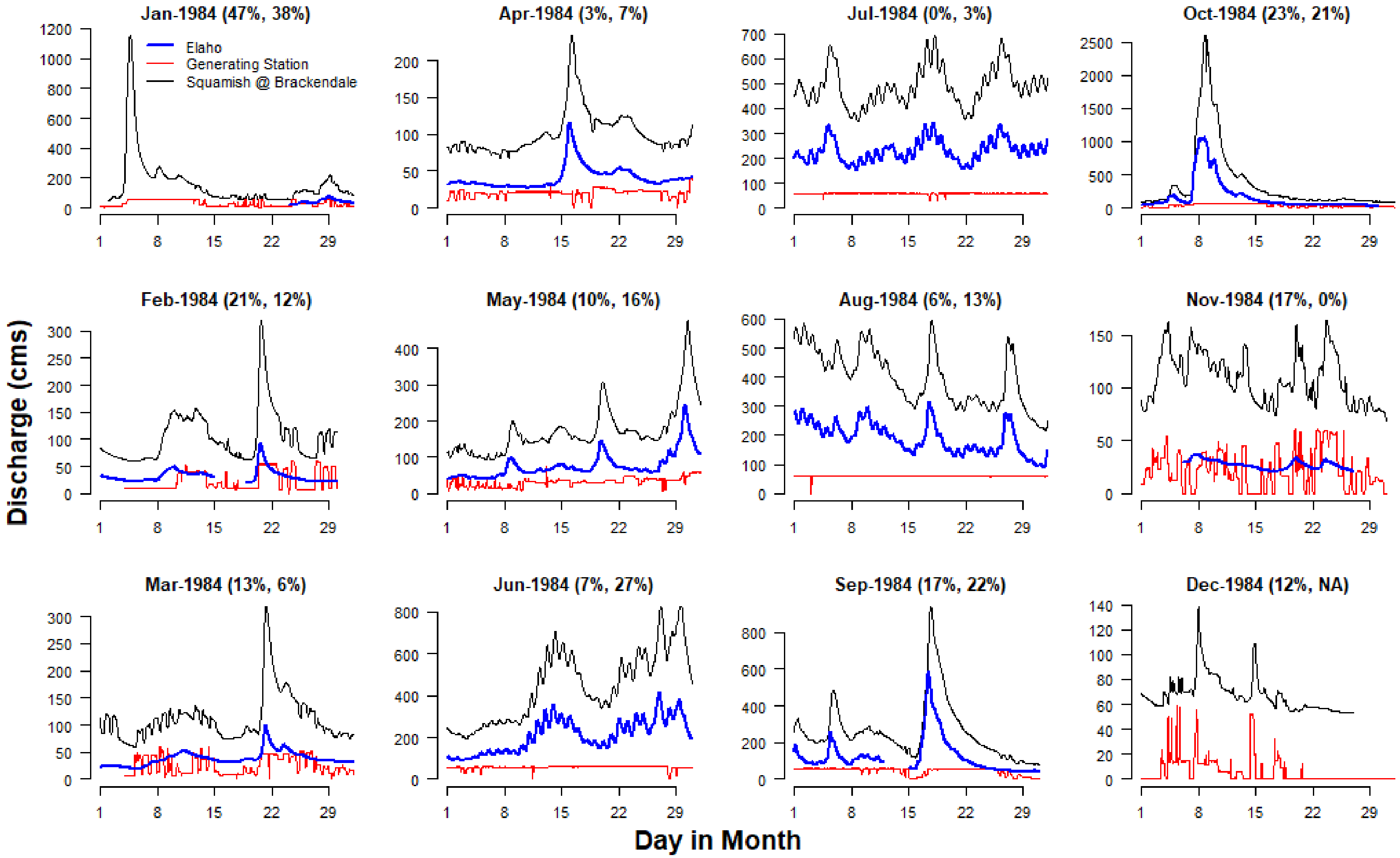
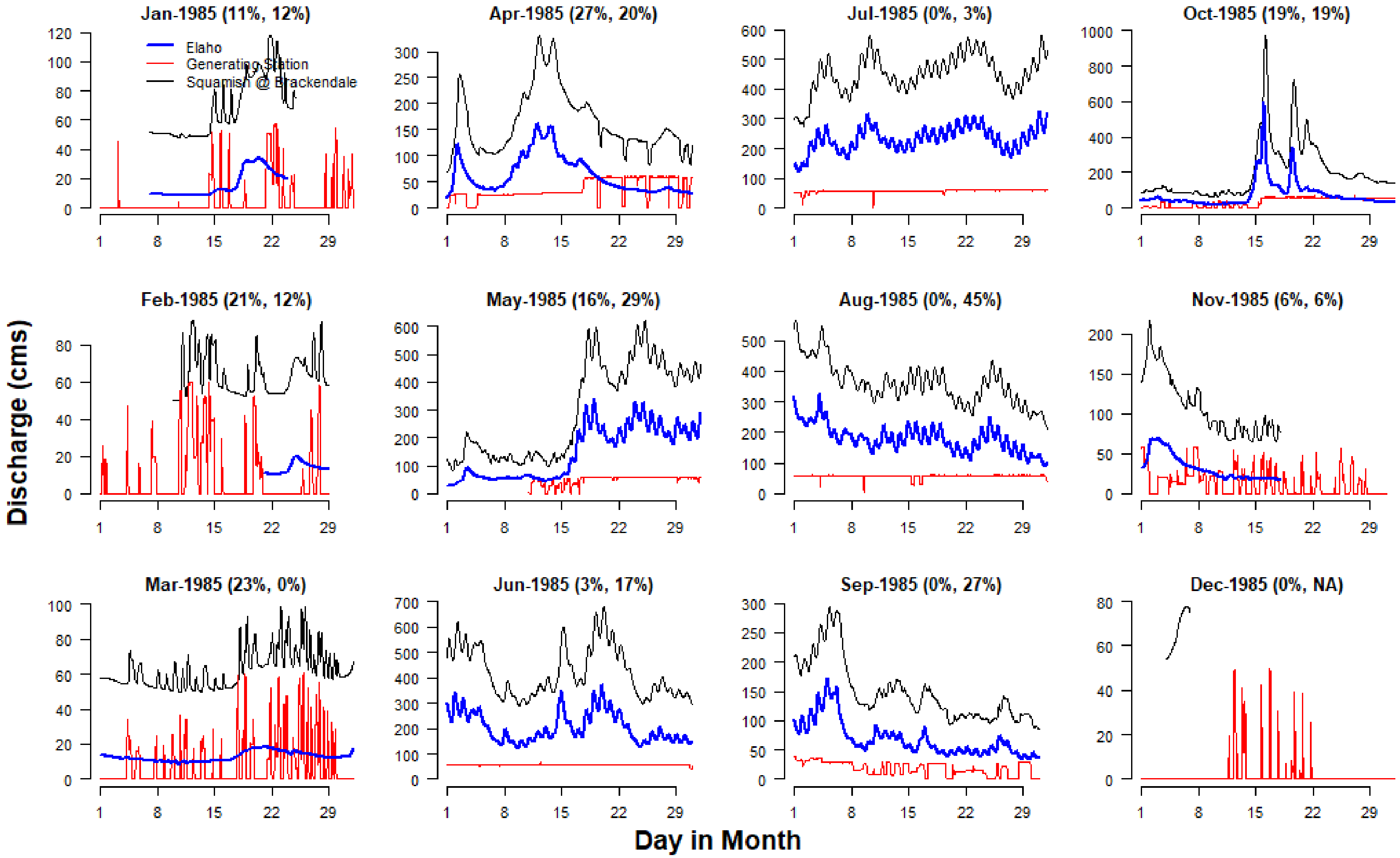


Figure 7. Comparison of hourly trends in discharge (Q) at the Brackendale gauge on the Squamish River in the first week of March (blue line) and the first week of August (red line) in 2017. Light grey and dark grey rectangles identify the period between sunrise and sunset in March and August, respectively.

Figure A1. Monthly trends in hourly discharge from the Cheakamus generating station (red lines), the Elaho River near its mouth (blue lines), and in the Squamish River at the Brackendale gauge (black lines). Values in parentheses denote the percentage of days when the peak-to-base flow ratio is greater than 1.5 for the Squamish River at the Brackendale gauge (left %) and for the Elaho River (right %).


Jan-1984 (47%, 38%)
Apr-1984 (3%, 7%)
Jul-1984 (0%, 3%)
Oct-1984 (23%, 21%)
Feb-1984 (21%, 12%)
May-1984 (10%, 16%)
Aug-1984 (6%, 13%)
Nov-1984 (17%, 0%)
Mar-1984 (13%, 6%)
Jun-1984 (7%, 27%)
Sep-1984 (17%, 22%)
Dec-1984 (12%, NA)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1985 (11%, 12%)
Apr-1985 (27%, 20%)
Jul-1985 (0%, 3%)
Oct-1985 (19%, 19%)
Feb-1985 (21%, 12%)
May-1985 (16%, 29%)
Aug-1985 (0%, 45%)
Nov-1985 (6%, 6%)
Mar-1985 (23%, 0%)
Jun-1985 (3%, 17%)
Sep-1985 (0%, 27%)
Dec-1985 (0%, NA)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
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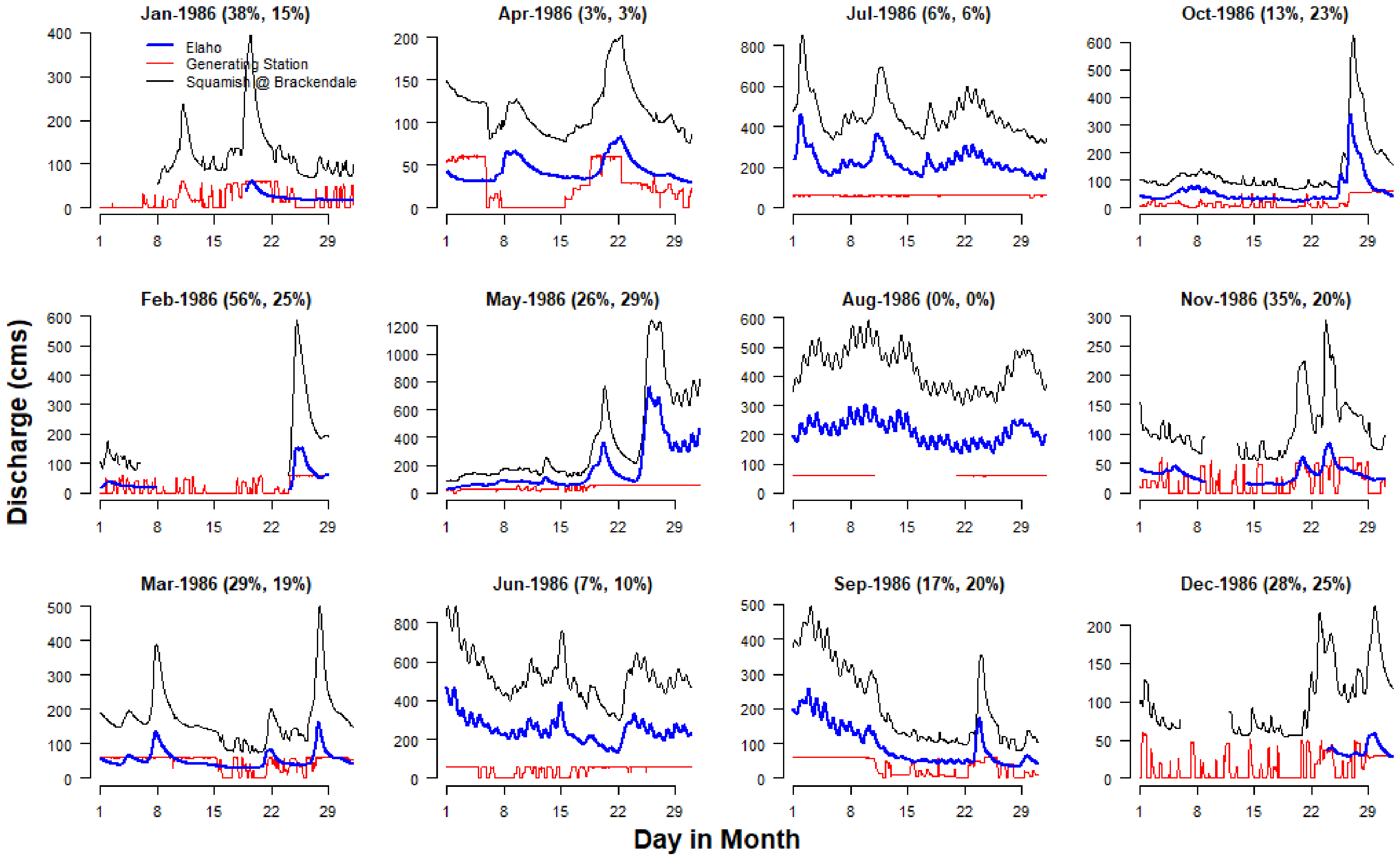
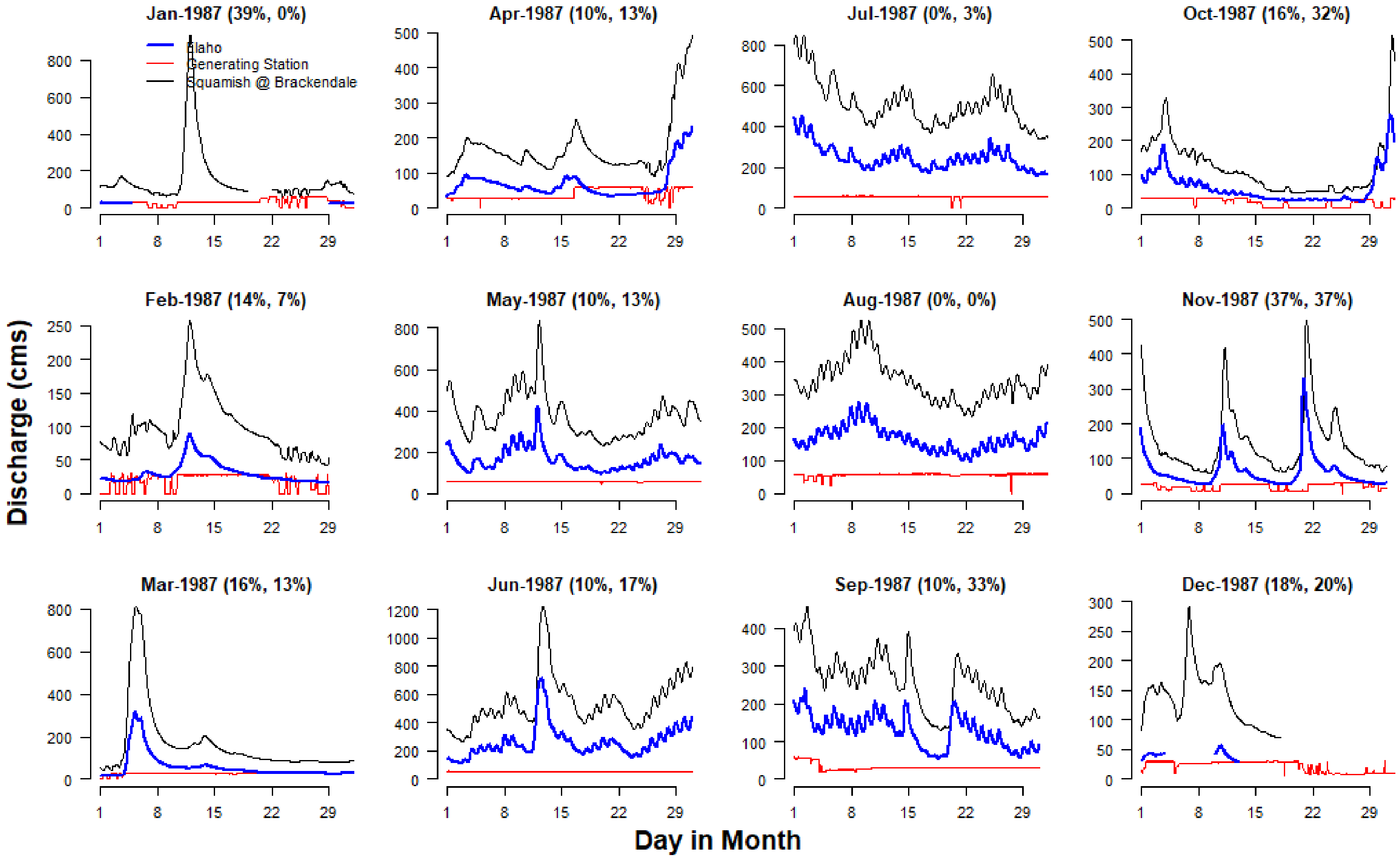
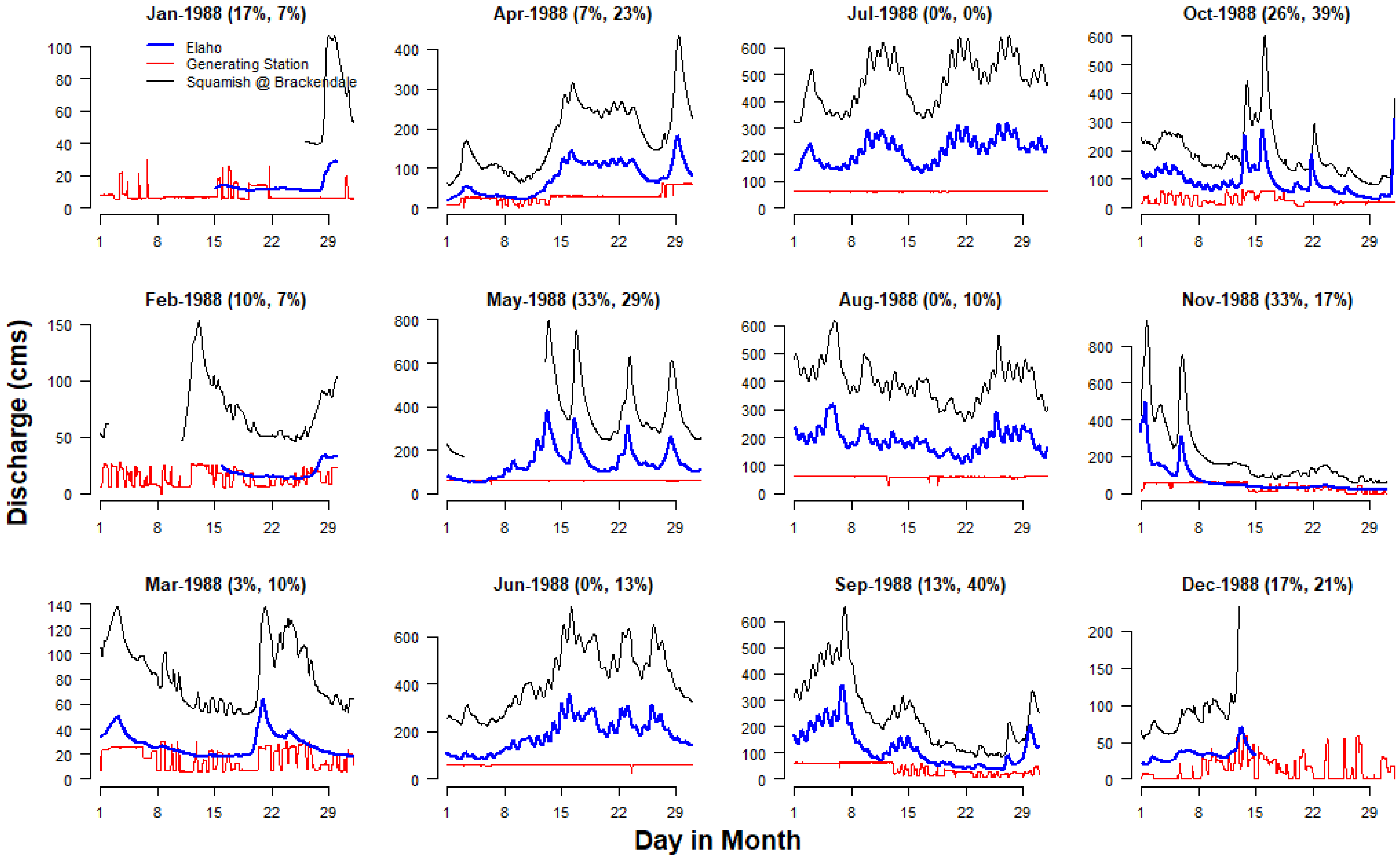
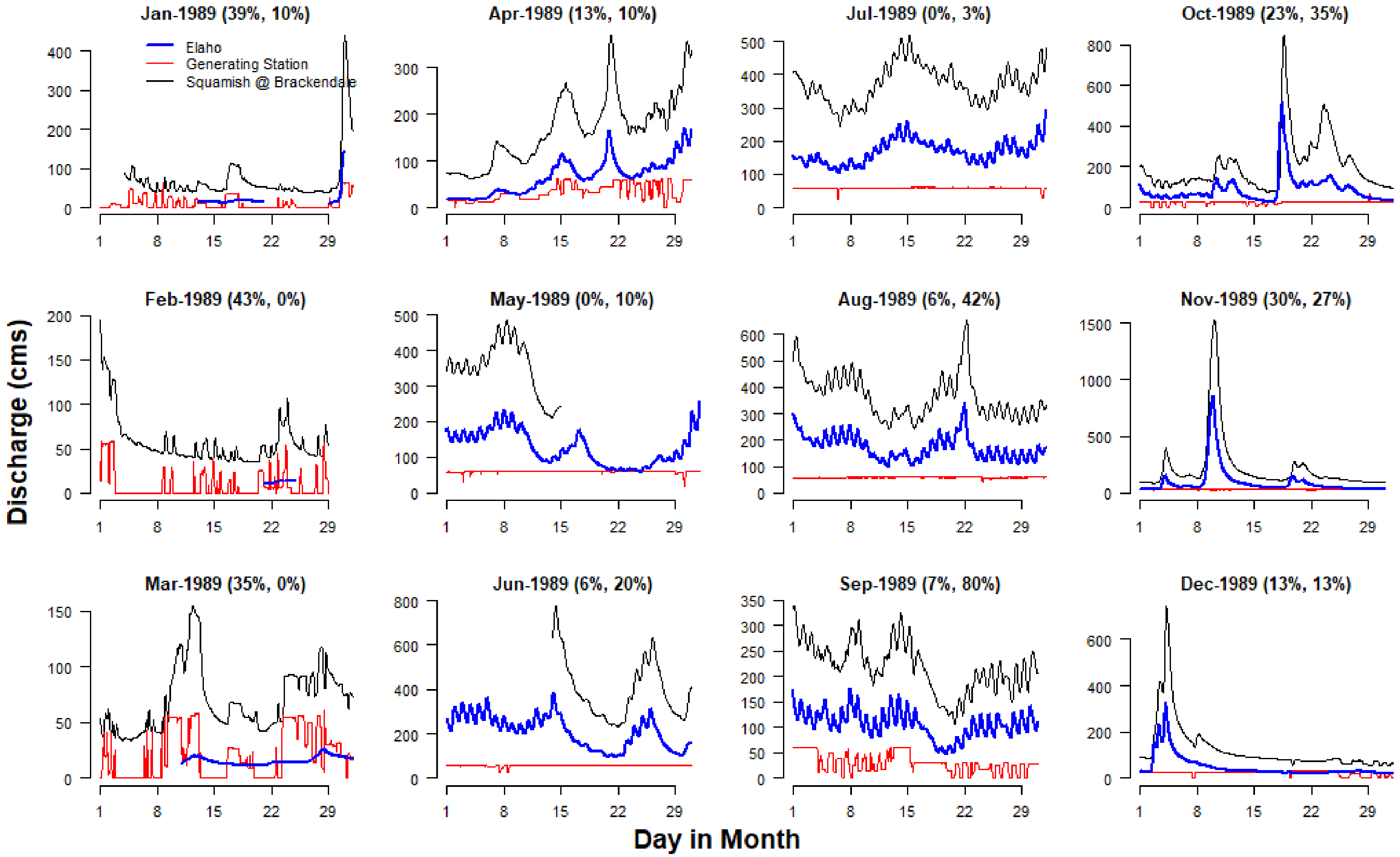
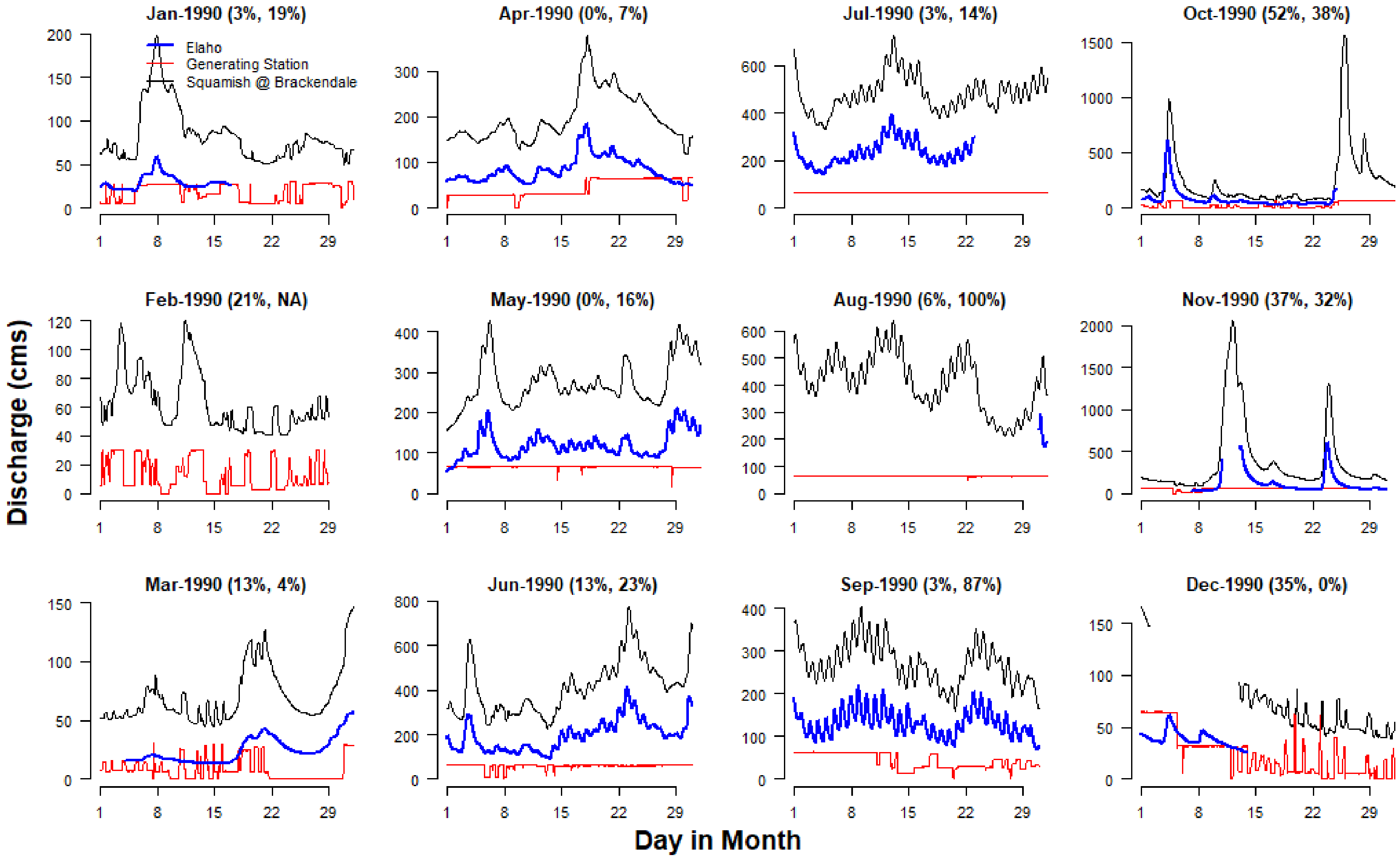
22
29

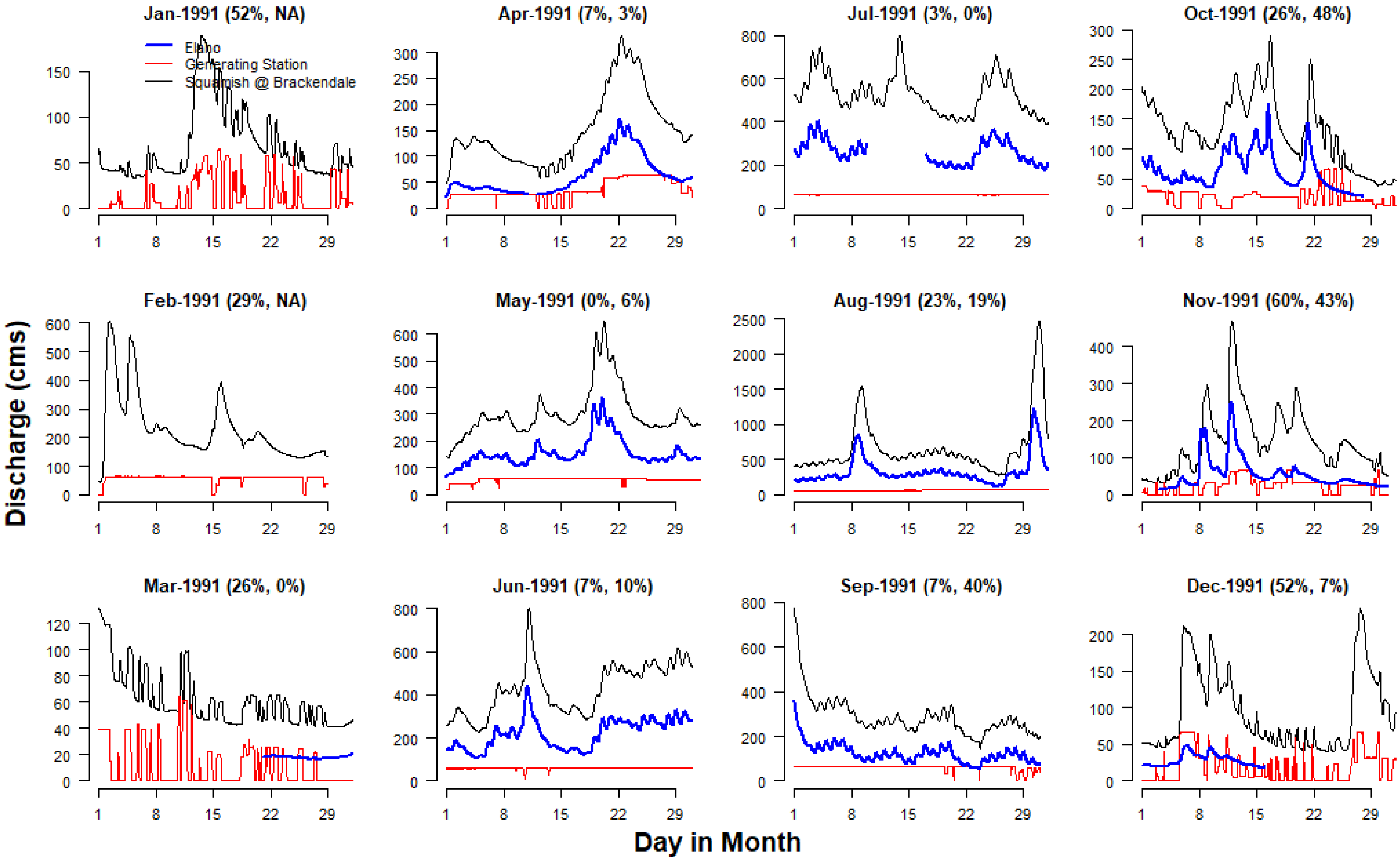

Jan-1986 (38%, 15%)
Apr-1986 (3%, 3%)
Jul-1986 (6%, 6%)
Oct-1986 (13%, 23%)
Feb-1986 (56%, 25%)
May-1986 (26%, 29%)
Aug-1986 (0%, 0%)
Nov-1986 (35%, 20%)
Mar-1986 (29%, 19%)
Jun-1986 (7%, 10%)
Sep-1986 (17%, 20%)
Dec-1986 (28%, 25%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

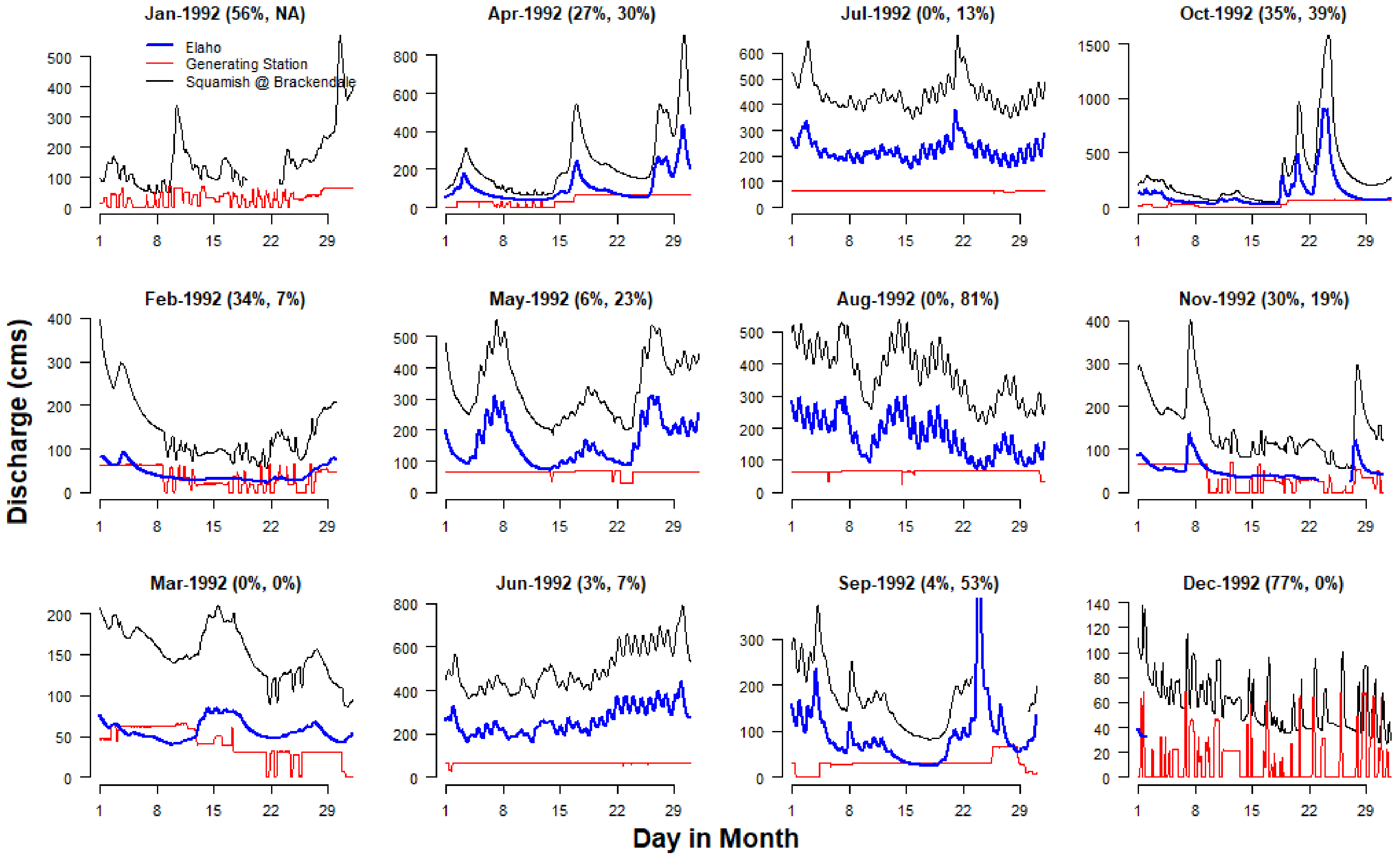

Jan-1987 (39%, 0%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1987 (10%, 13%)
Jul-1987 (0%, 3%)
Oct-1987 (16%, 32%)
Feb-1987 (14%, 7%)
May-1987 (10%, 13%)
Aug-1987 (0%, 0%)
Nov-1987 (37%, 37%)
Mar-1987 (16%, 13%)
Jun-1987 (10%, 17%)
Sep-1987 (10%, 33%)
Dec-1987 (18%, 20%)
Discharge (cms)
Day in Month
1
8
15
22
29

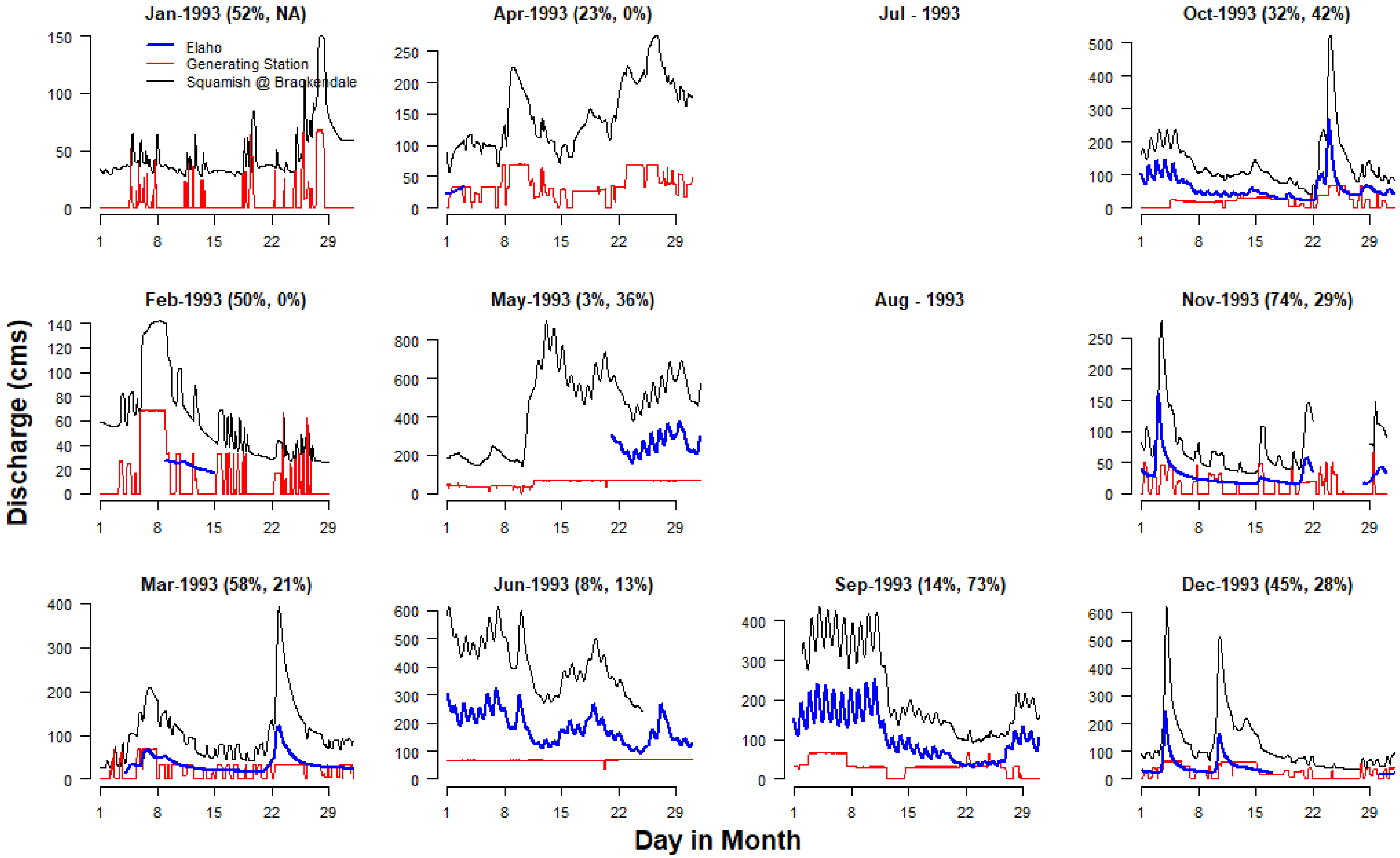

Jan-1988 (17%, 7%)
Apr-1988 (7%, 23%)
Jul-1988 (0%, 0%)
Oct-1988 (26%, 39%)
Feb-1988 (10%, 7%)
May-1988 (33%, 29%)
Aug-1988 (0%, 10%)
Nov-1988 (33%, 17%)
Mar-1988 (3%, 10%)
Jun-1988 (0%, 13%)
Sep-1988 (13%, 40%)
Dec-1988 (17%, 21%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1989 (39%, 10%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1989 (13%, 10%)
Jul-1989 (0%, 3%)
Oct-1989 (23%, 35%)
Feb-1989 (43%, 0%)
May-1989 (0%, 10%)
Aug-1989 (6%, 42%)
Nov-1989 (30%, 27%)
Mar-1989 (35%, 0%)
Jun-1989 (6%, 20%)
Sep-1989 (7%, 80%)
Dec-1989 (13%, 13%)
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1990 (3%, 19%)
Apr-1990 (0%, 7%)
Jul-1990 (3%, 14%)
Oct-1990 (52%, 38%)
Feb-1990 (21%, NA)
May-1990 (0%, 16%)
Aug-1990 (6%, 100%)
Nov-1990 (37%, 32%)
Mar-1990 (13%, 4%)
Jun-1990 (13%, 23%)
Sep-1990 (3%, 87%)
Dec-1990 (35%, 0%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1991 (52%, NA)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1991 (7%, 3%)
Jul-1991 (3%, 0%)
Oct-1991 (26%, 48%)
Feb-1991 (29%, NA)
May-1991 (0%, 6%)
Aug-1991 (23%, 19%)
Nov-1991 (60%, 43%)
Mar-1991 (26%, 0%)
Jun-1991 (7%, 10%)
Sep-1991 (7%, 40%)
Dec-1991 (52%, 7%)
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1992 (56%, NA)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1992 (27%, 30%)
Jul-1992 (0%, 13%)
Oct-1992 (35%, 39%)
Feb-1992 (34%, 7%)
May-1992 (6%, 23%)
Aug-1992 (0%, 81%)
Nov-1992 (30%, 19%)
Mar-1992 (0%, 0%)
Jun-1992 (3%, 7%)
Sep-1992 (4%, 53%)
Dec-1992 (77%, 0%)
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-1993 (52%, NA)

Apr-1993 (23%, 0%)

Jul - 1993

Oct-1993 (32%, 42%)

Feb-1993 (50%, 0%)

May-1993 (3%, 36%)

Aug - 1993

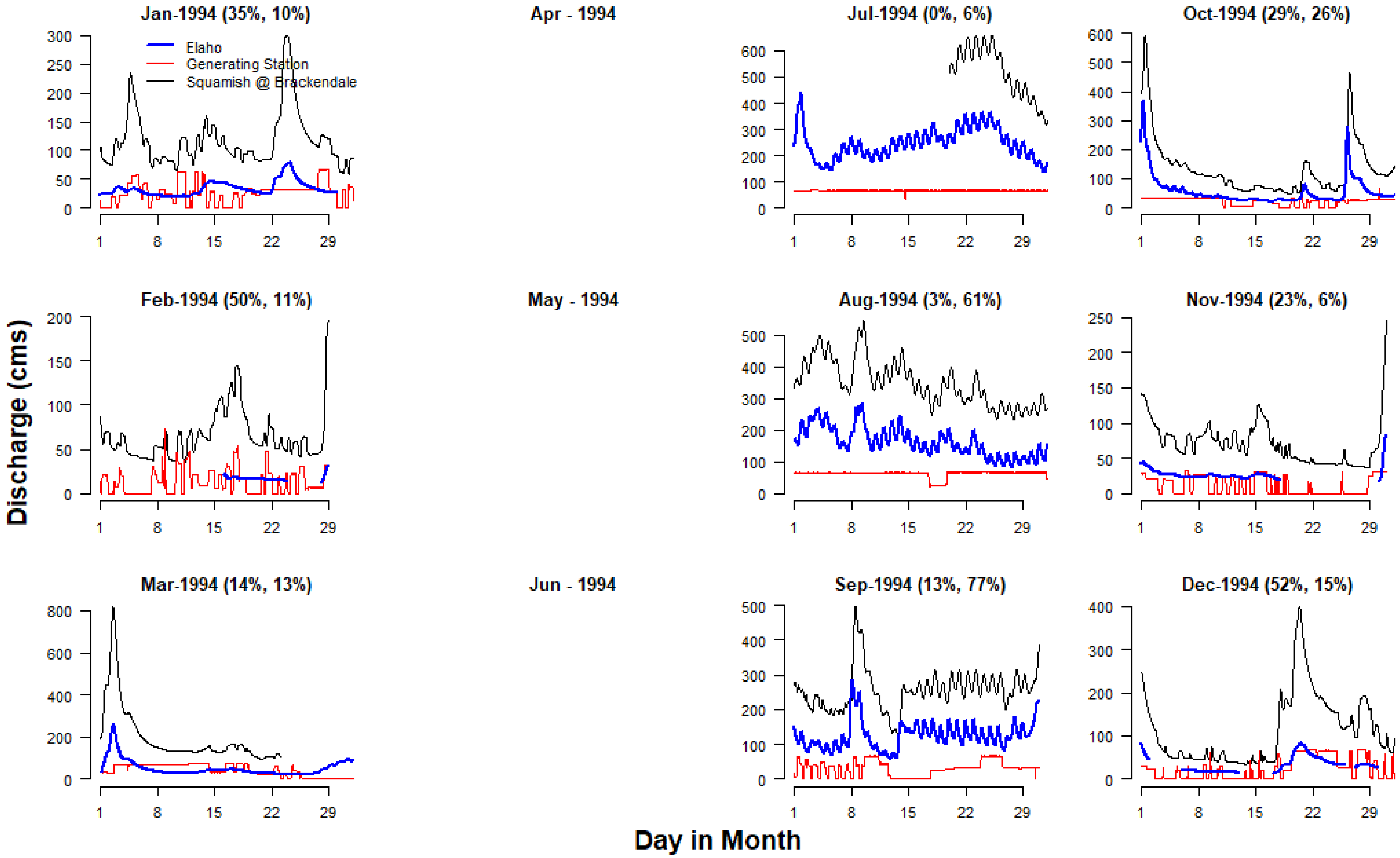
Nov-1993 (74%, 29%)

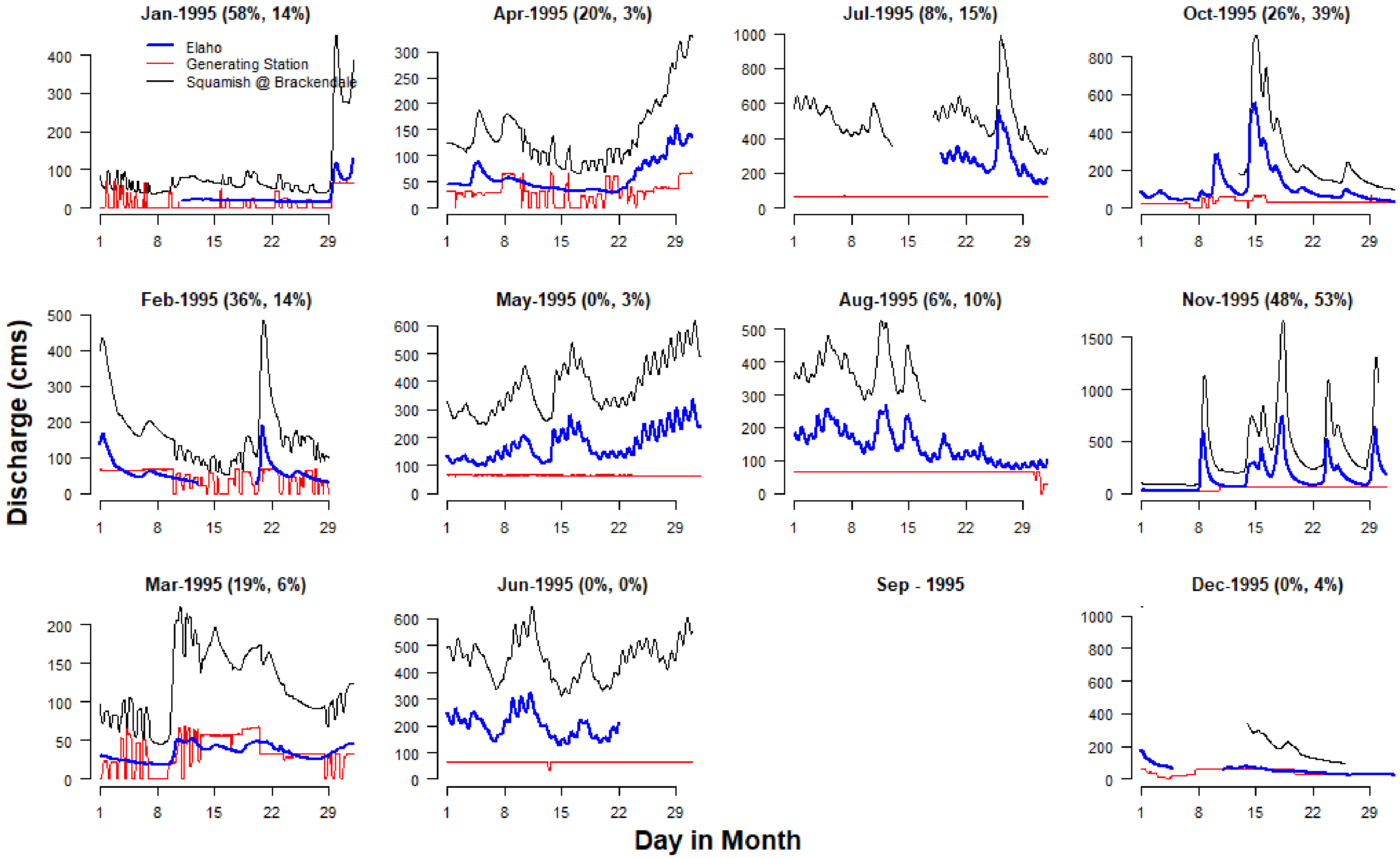
Mar-1993 (58%, 21%)

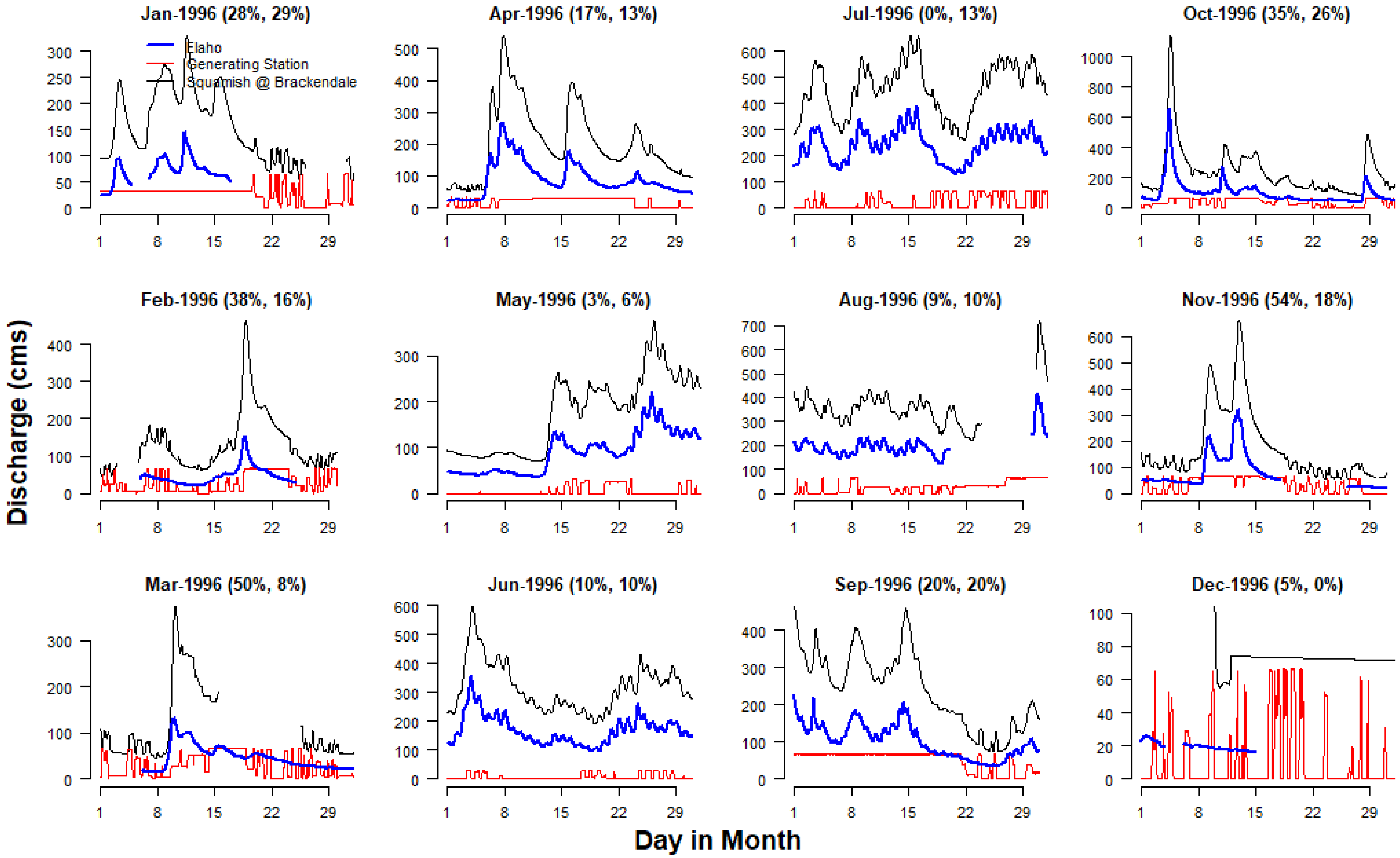
Jun-1993 (8%, 13%)

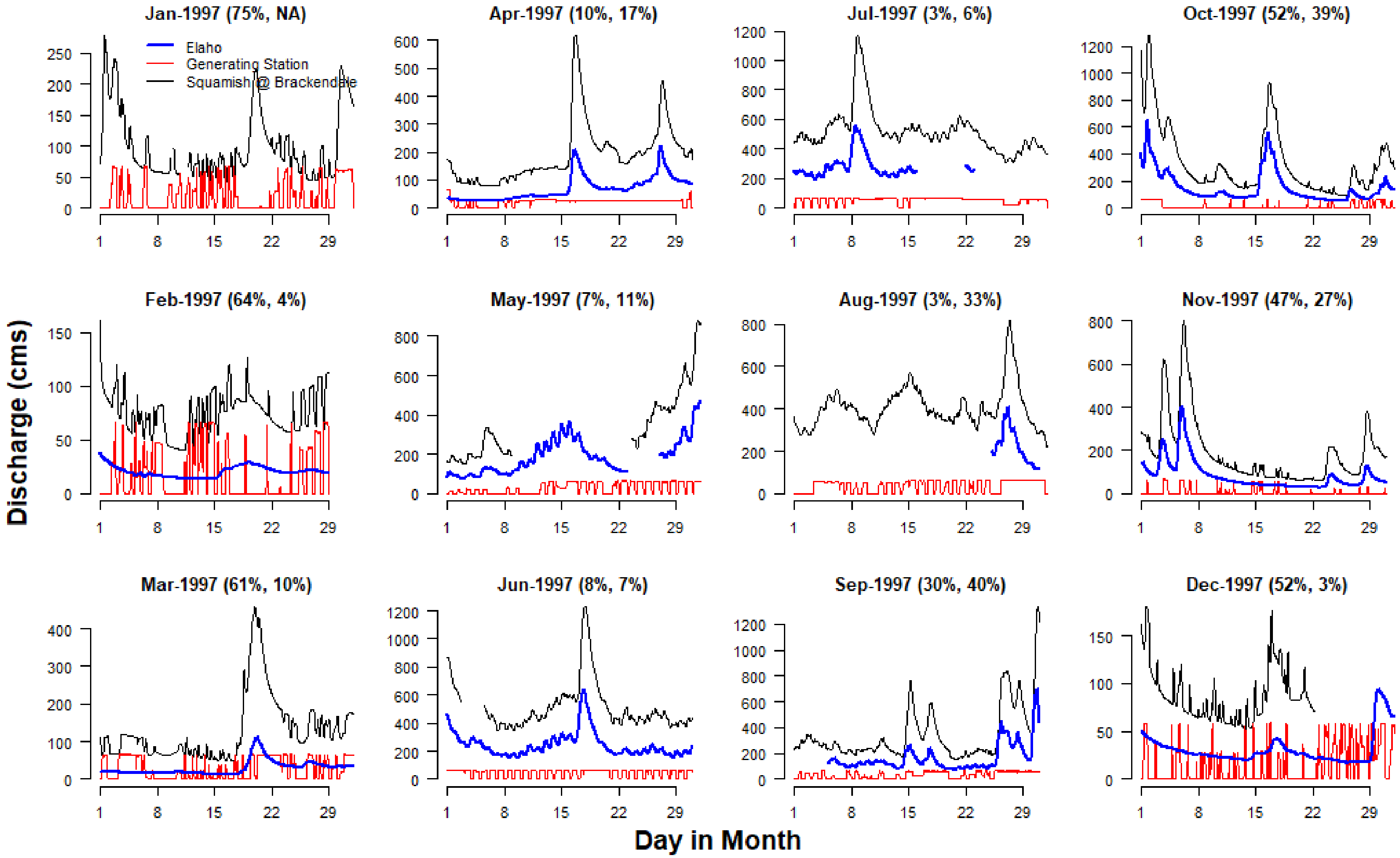
Sep-1993 (14%, 73%)

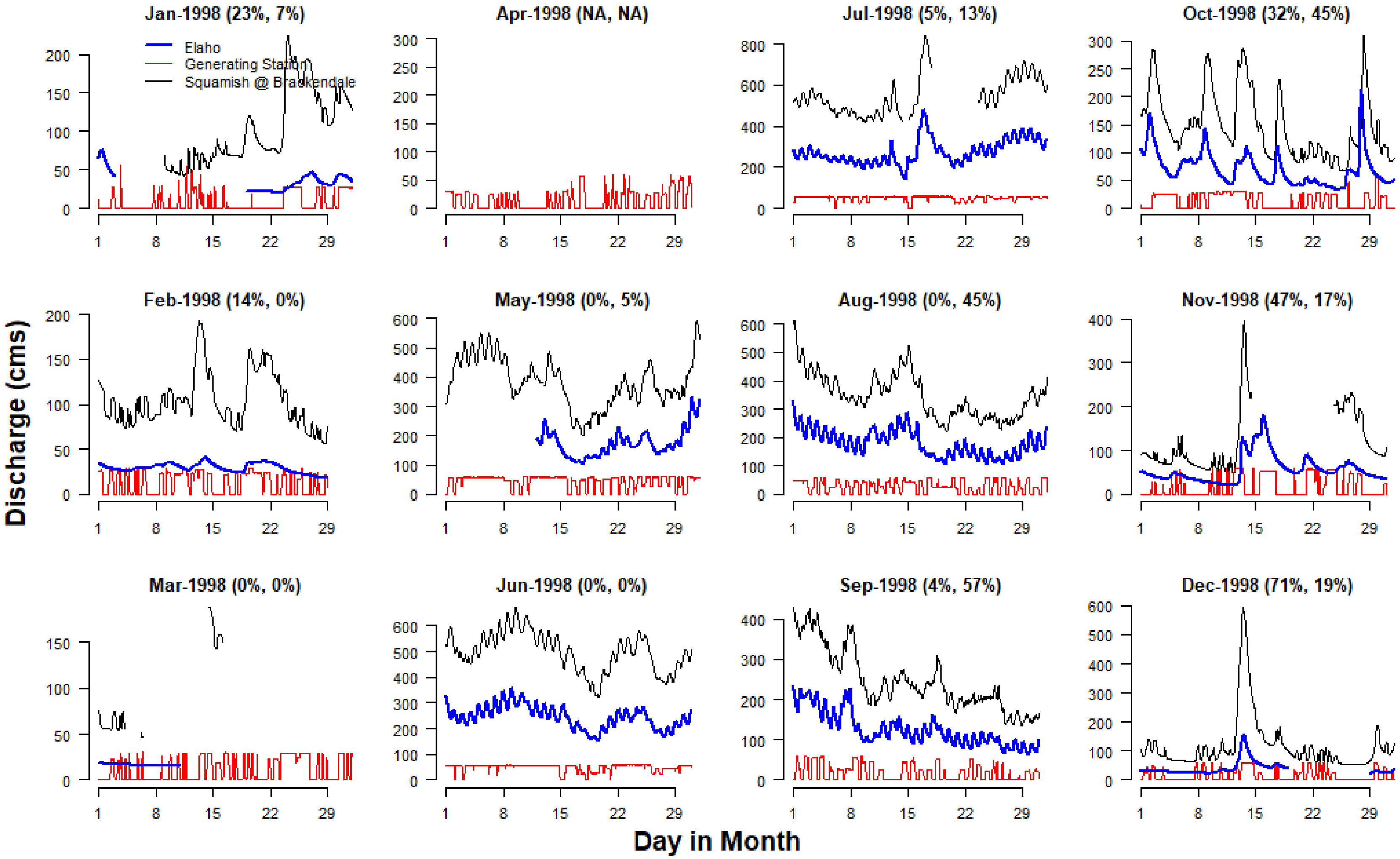
Dec-1993 (45%, 28%)

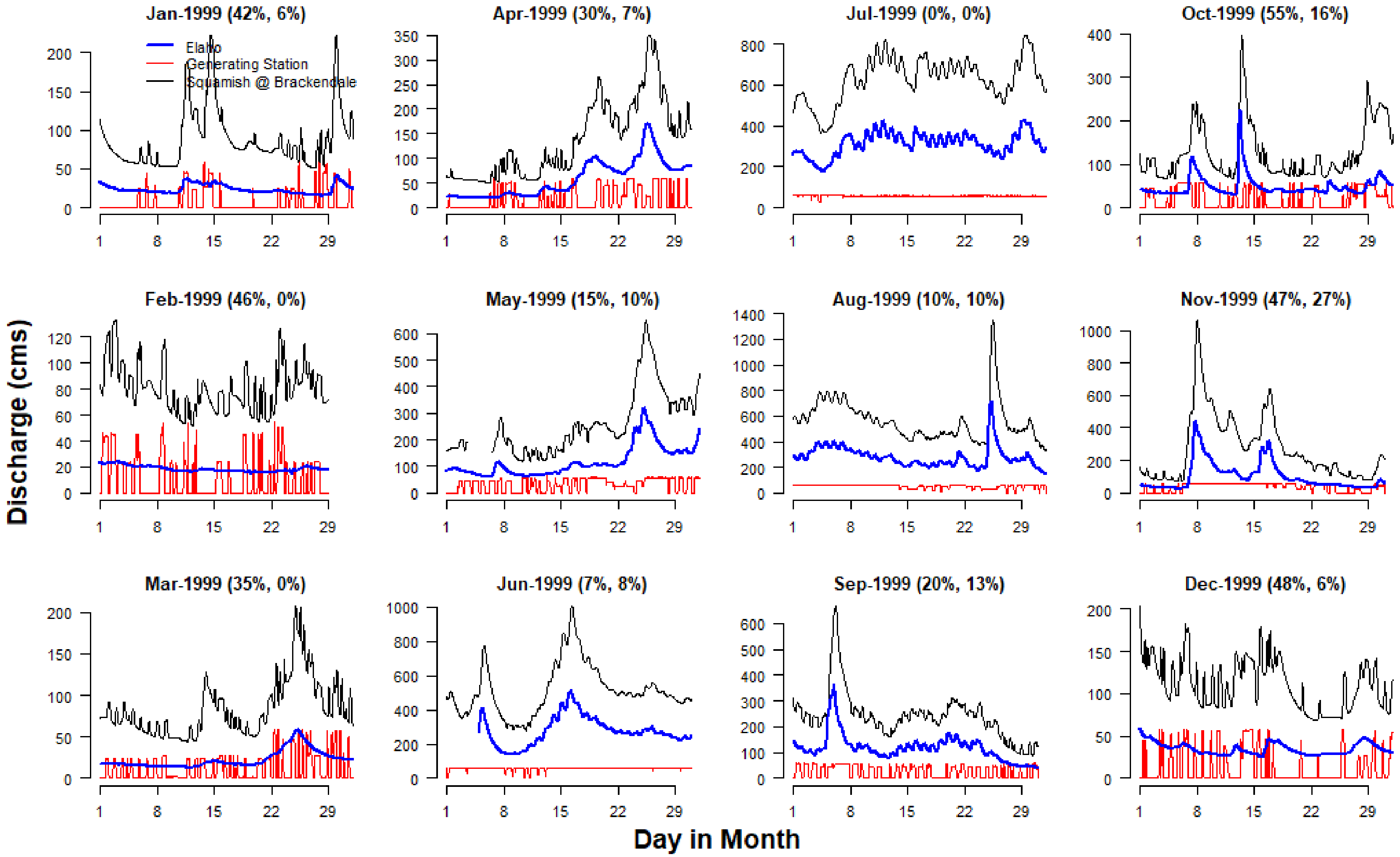

Jan-1994 (35%, 10%)
Elaho
Generating Station
Squamish @ Brackendale
Apr - 1994
Jul-1994 (0%, 6%)
Oct-1994 (29%, 26%)
Feb-1994 (50%, 11%)
May - 1994
Aug-1994 (3%, 61%)
Nov-1994 (23%, 6%)
Mar-1994 (14%, 13%)
Jun - 1994
Sep-1994 (13%, 77%)
Dec-1994 (52%, 15%)
Discharge (cms)
Day in Month
1
8
15
22
29

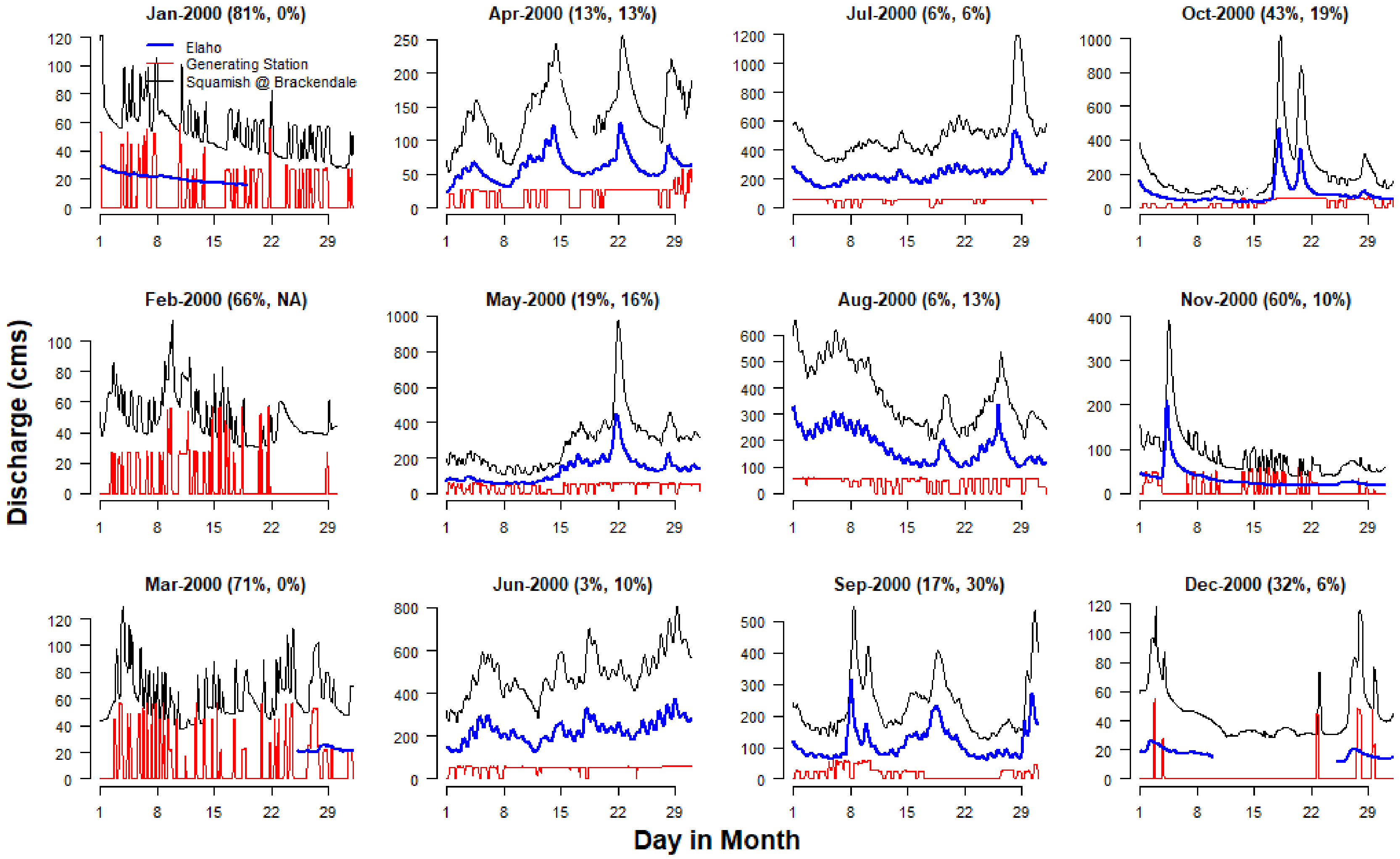

Jan-1995 (58%, 14%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1995 (20%, 3%)
Jul-1995 (8%, 15%)
Oct-1995 (26%, 39%)
Feb-1995 (36%, 14%)
May-1995 (0%, 3%)
Aug-1995 (6%, 10%)
Nov-1995 (48%, 53%)
Mar-1995 (19%, 6%)
Jun-1995 (0%, 0%)
Sep - 1995
Dec-1995 (0%, 4%)
Discharge (cms)
Day in Month
1
8
15
22
29

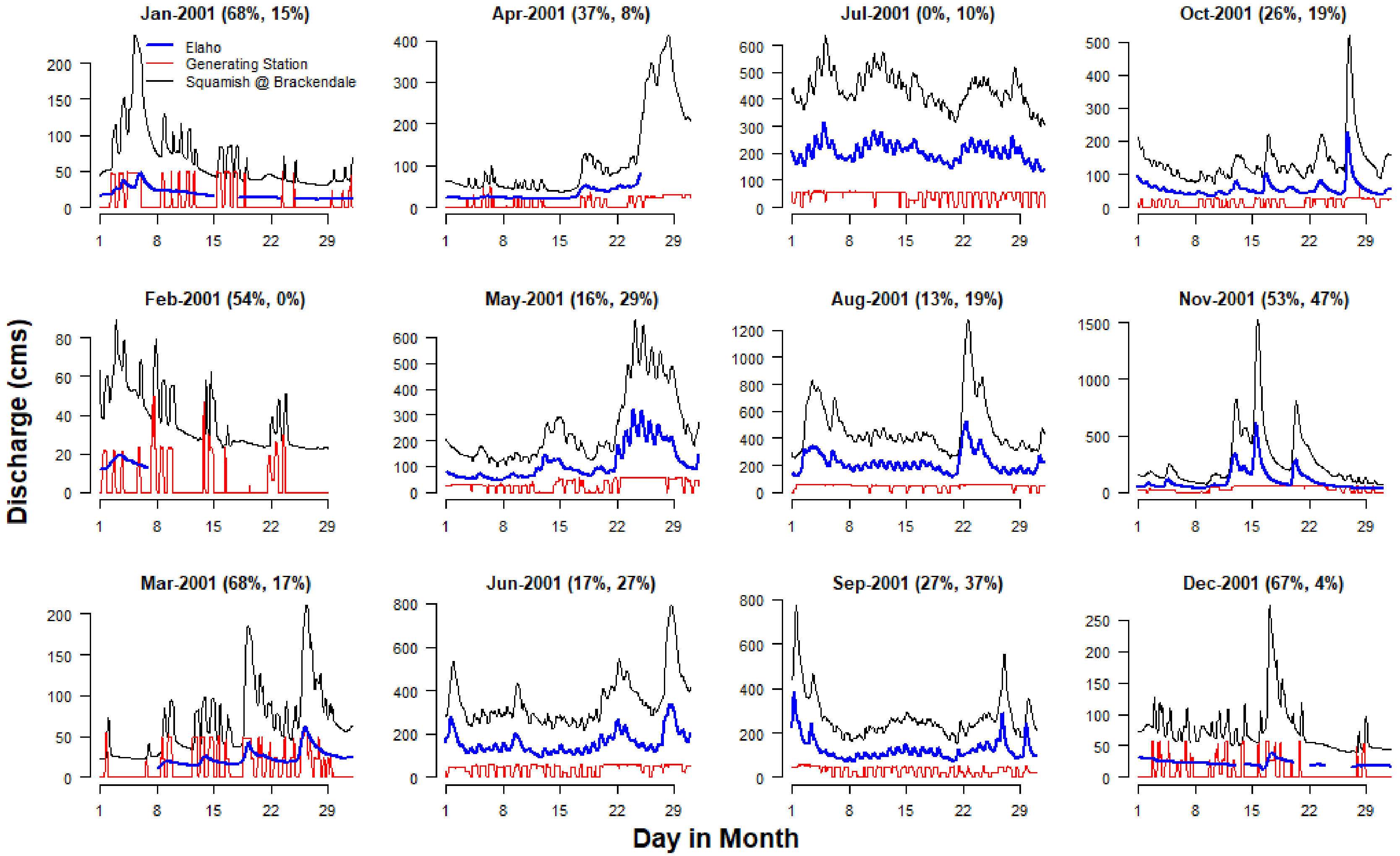

Jan-1996 (28%, 29%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1996 (17%, 13%)
Jul-1996 (0%, 13%)
Oct-1996 (35%, 26%)
Feb-1996 (38%, 16%)
May-1996 (3%, 6%)
Aug-1996 (9%, 10%)
Nov-1996 (54%, 18%)
Mar-1996 (50%, 8%)
Jun-1996 (10%, 10%)
Sep-1996 (20%, 20%)
Dec-1996 (5%, 0%)
Discharge (cms)
Day in Month
1
8
15
22
29

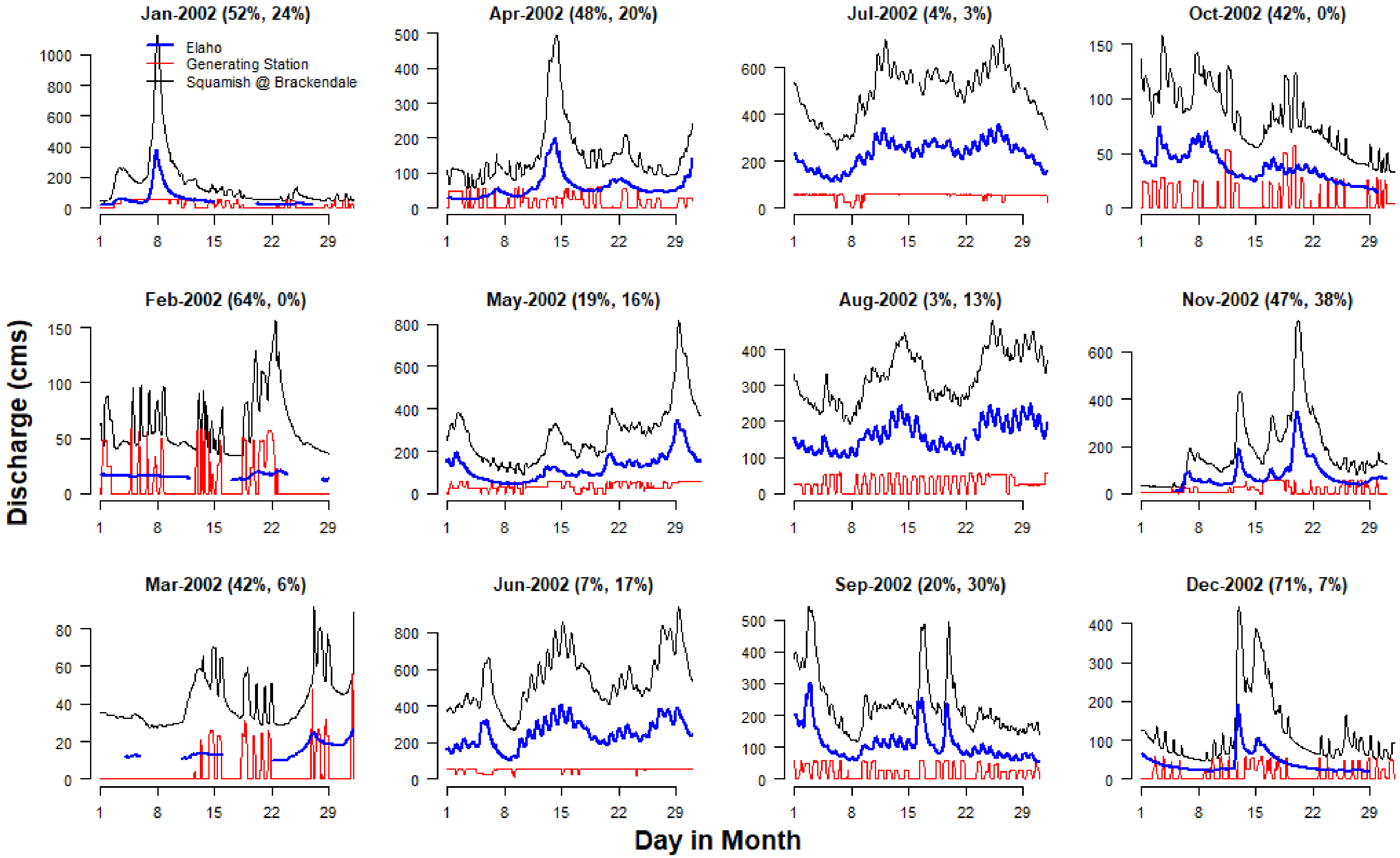

Jan-1997 (75%, NA)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1997 (10%, 17%)
Jul-1997 (3%, 6%)
Oct-1997 (52%, 39%)
Feb-1997 (64%, 4%)
May-1997 (7%, 11%)
Aug-1997 (3%, 33%)
Nov-1997 (47%, 27%)
Mar-1997 (61%, 10%)
Jun-1997 (8%, 7%)
Sep-1997 (30%, 40%)
Dec-1997 (52%, 3%)
Discharge (cms)
Day in Month
1
8
15
22
29

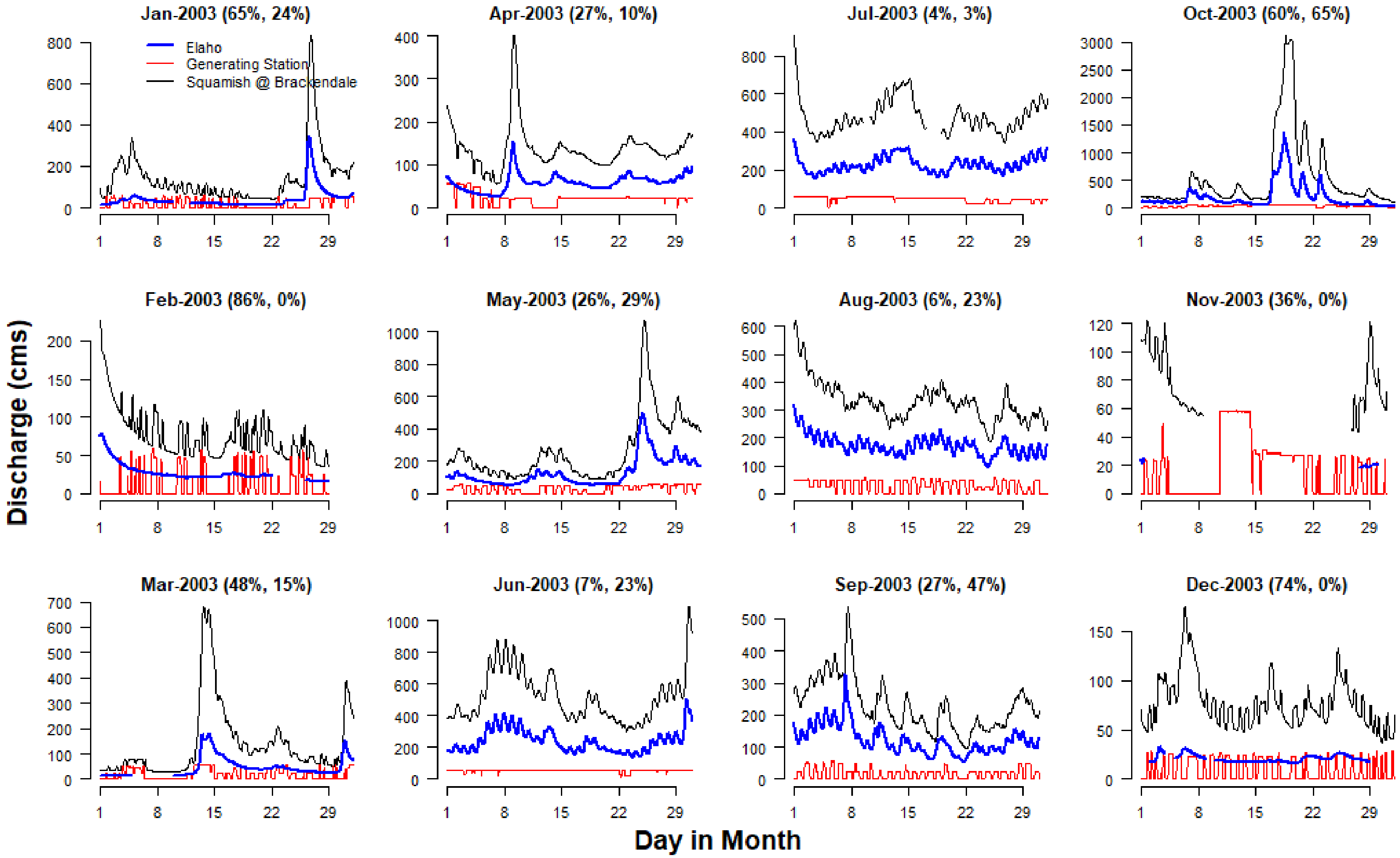

Jan-1998 (23%, 7%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-1998 (NA, NA)
Jul-1998 (5%, 13%)
Oct-1998 (32%, 45%)
Feb-1998 (14%, 0%)
May-1998 (0%, 5%)
Aug-1998 (0%, 45%)
Nov-1998 (47%, 17%)
Mar-1998 (0%, 0%)
Jun-1998 (0%, 0%)
Sep-1998 (4%, 57%)
Dec-1998 (71%, 19%)
Discharge (cms)
Day in Month
1
8
15
22
29

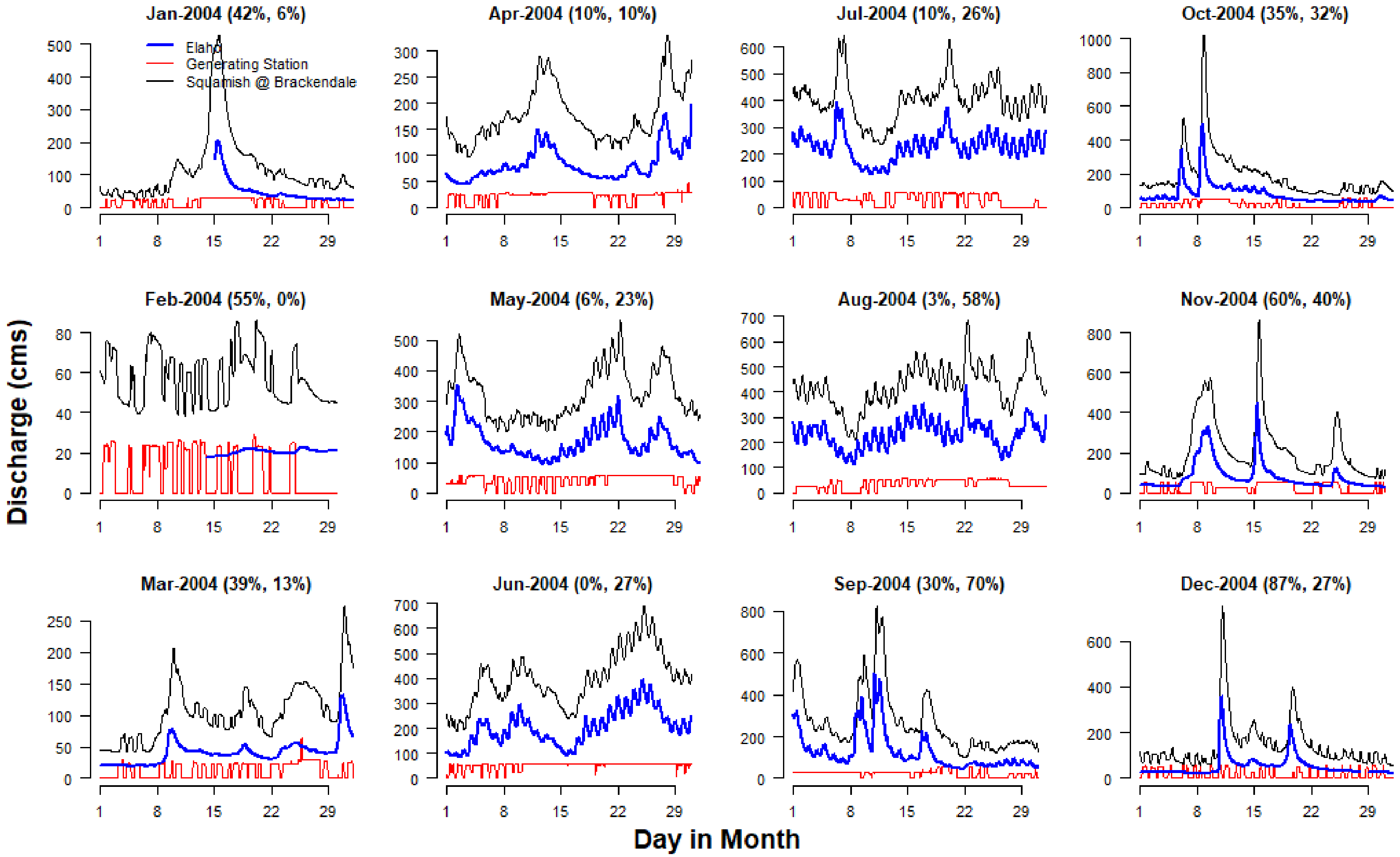

Jan-1999 (42%, 6%)
Apr-1999 (30%, 7%)
Jul-1999 (0%, 0%)
Oct-1999 (55%, 16%)
Feb-1999 (46%, 0%)
May-1999 (15%, 10%)
Aug-1999 (10%, 10%)
Nov-1999 (47%, 27%)
Mar-1999 (35%, 0%)
Jun-1999 (7%, 8%)
Sep-1999 (20%, 13%)
Dec-1999 (48%, 6%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29
0
50
100
150
200
250
300
350
400
500
600
800
1000
1200
1400


Jan-2000 (81%, 0%)
Apr-2000 (13%, 13%)
Jul-2000 (6%, 6%)
Oct-2000 (43%, 19%)
Feb-2000 (66%, NA)
May-2000 (19%, 16%)
Aug-2000 (6%, 13%)
Nov-2000 (60%, 10%)
Mar-2000 (71%, 0%)
Jun-2000 (3%, 10%)
Sep-2000 (17%, 30%)
Dec-2000 (32%, 6%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

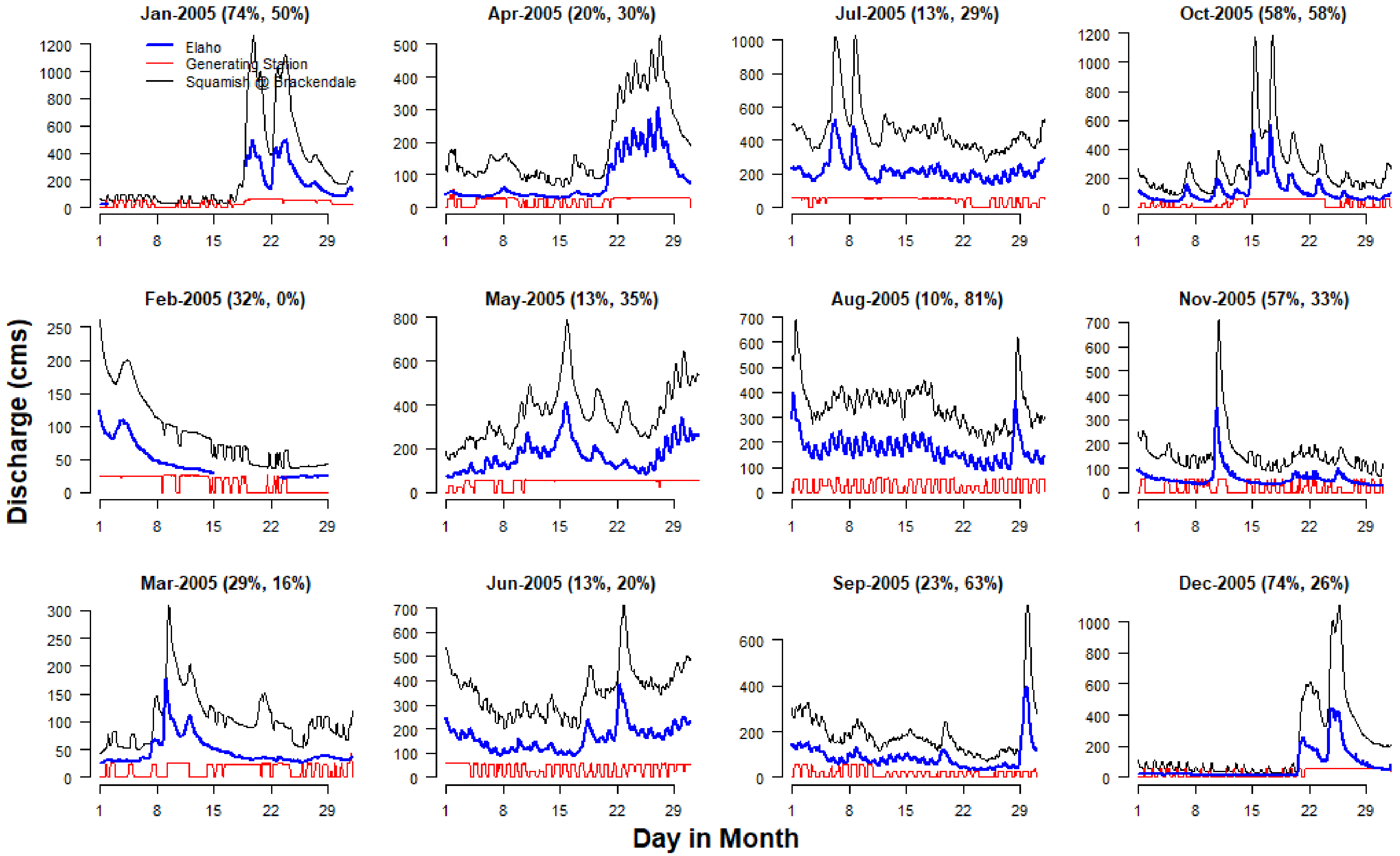

Jan-2001 (68%, 15%)
Apr-2001 (37%, 8%)
Jul-2001 (0%, 10%)
Oct-2001 (26%, 19%)
Feb-2001 (54%, 0%)
May-2001 (16%, 29%)
Aug-2001 (13%, 19%)
Nov-2001 (53%, 47%)
Mar-2001 (68%, 17%)
Jun-2001 (17%, 27%)
Sep-2001 (27%, 37%)
Dec-2001 (67%, 4%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

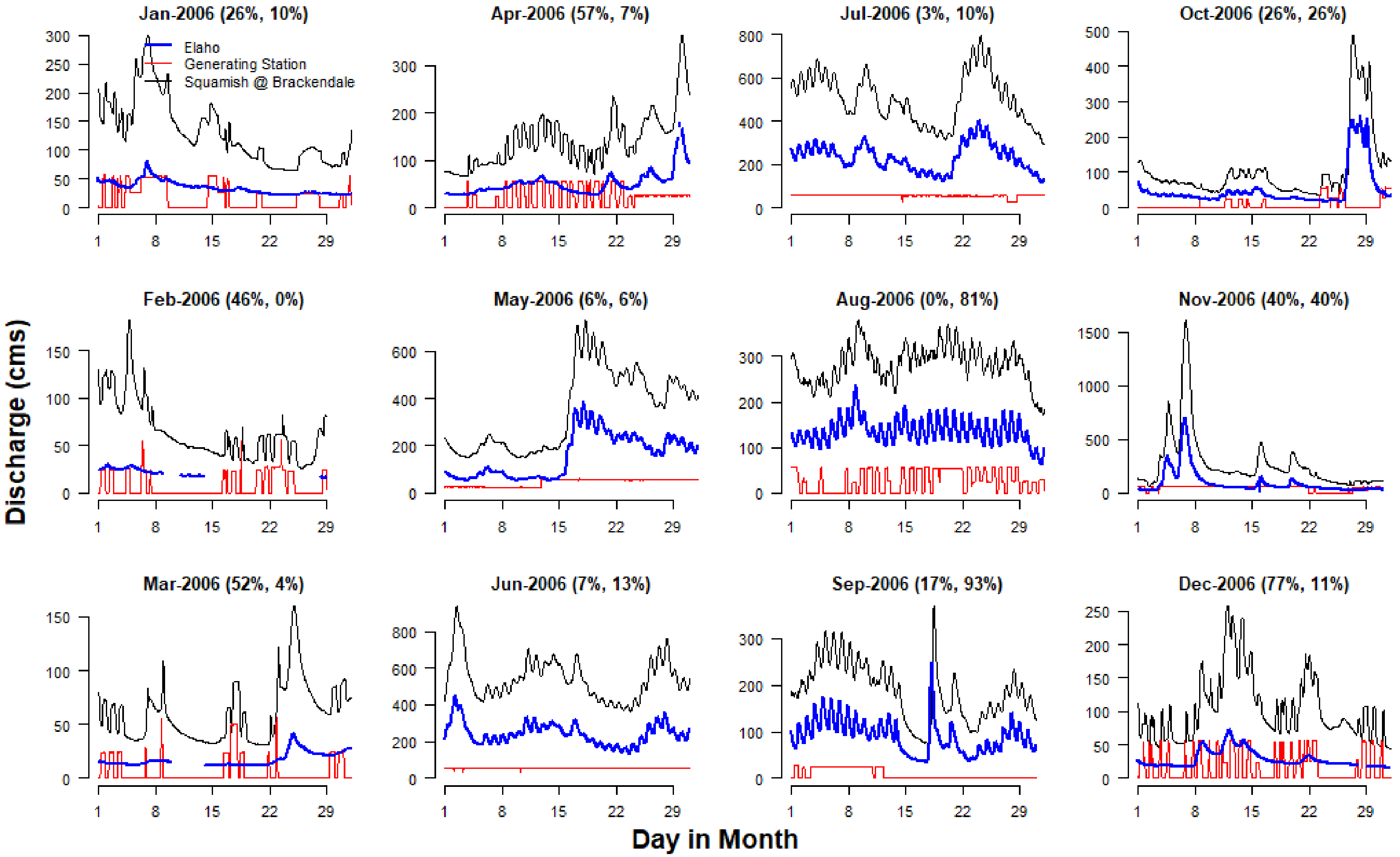

Jan-2002 (52%, 24%)
Apr-2002 (48%, 20%)
Jul-2002 (4%, 3%)
Oct-2002 (42%, 0%)
Feb-2002 (64%, 0%)
May-2002 (19%, 16%)
Aug-2002 (3%, 13%)
Nov-2002 (47%, 38%)
Mar-2002 (42%, 6%)
Jun-2002 (7%, 17%)
Sep-2002 (20%, 30%)
Dec-2002 (71%, 7%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

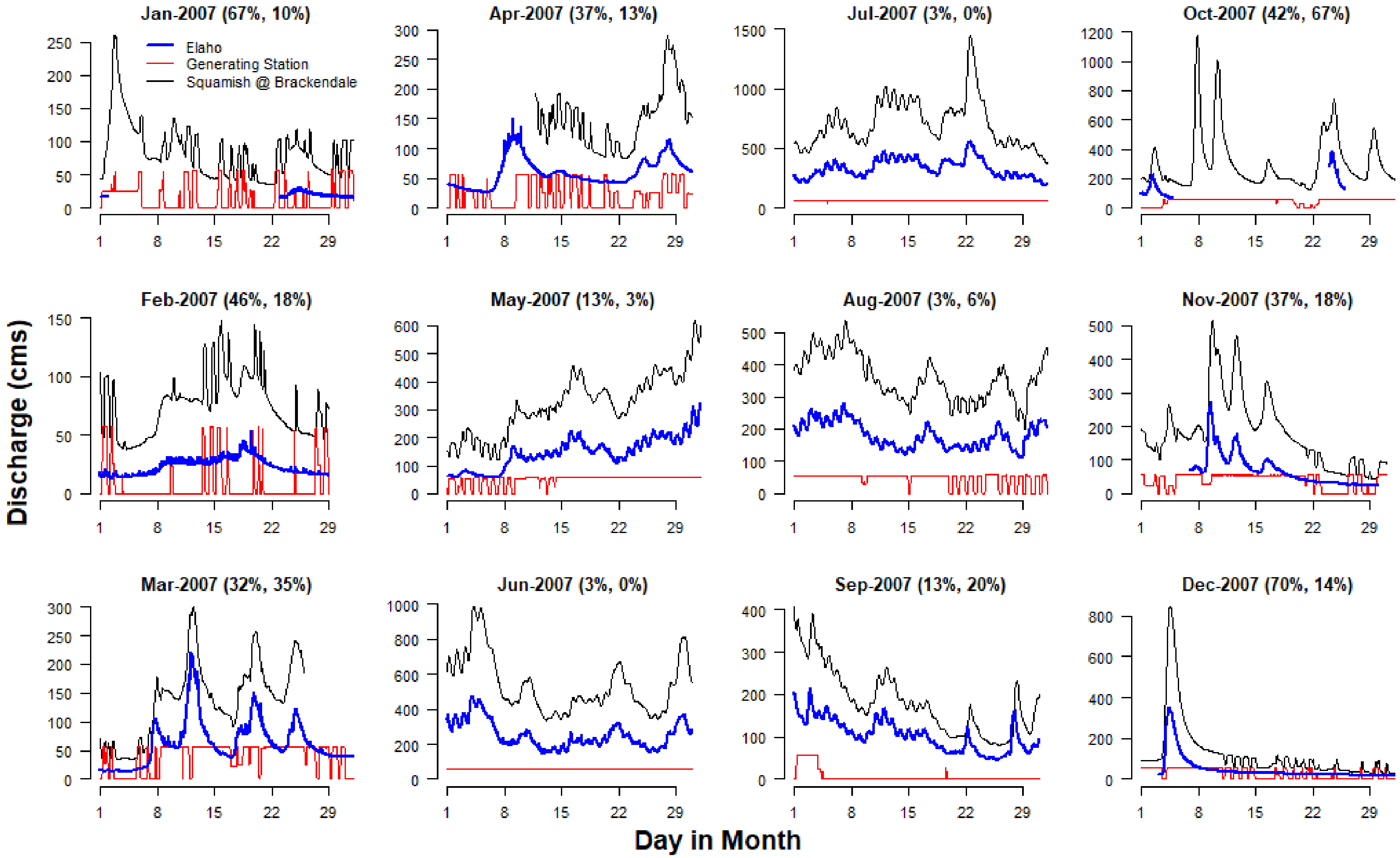

Jan-2003 (65%, 24%)
Apr-2003 (27%, 10%)
Jul-2003 (4%, 3%)
Oct-2003 (60%, 65%)
Feb-2003 (86%, 0%)
May-2003 (26%, 29%)
Aug-2003 (6%, 23%)
Nov-2003 (36%, 0%)
Mar-2003 (48%, 15%)
Jun-2003 (7%, 23%)
Sep-2003 (27%, 47%)
Dec-2003 (74%, 0%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

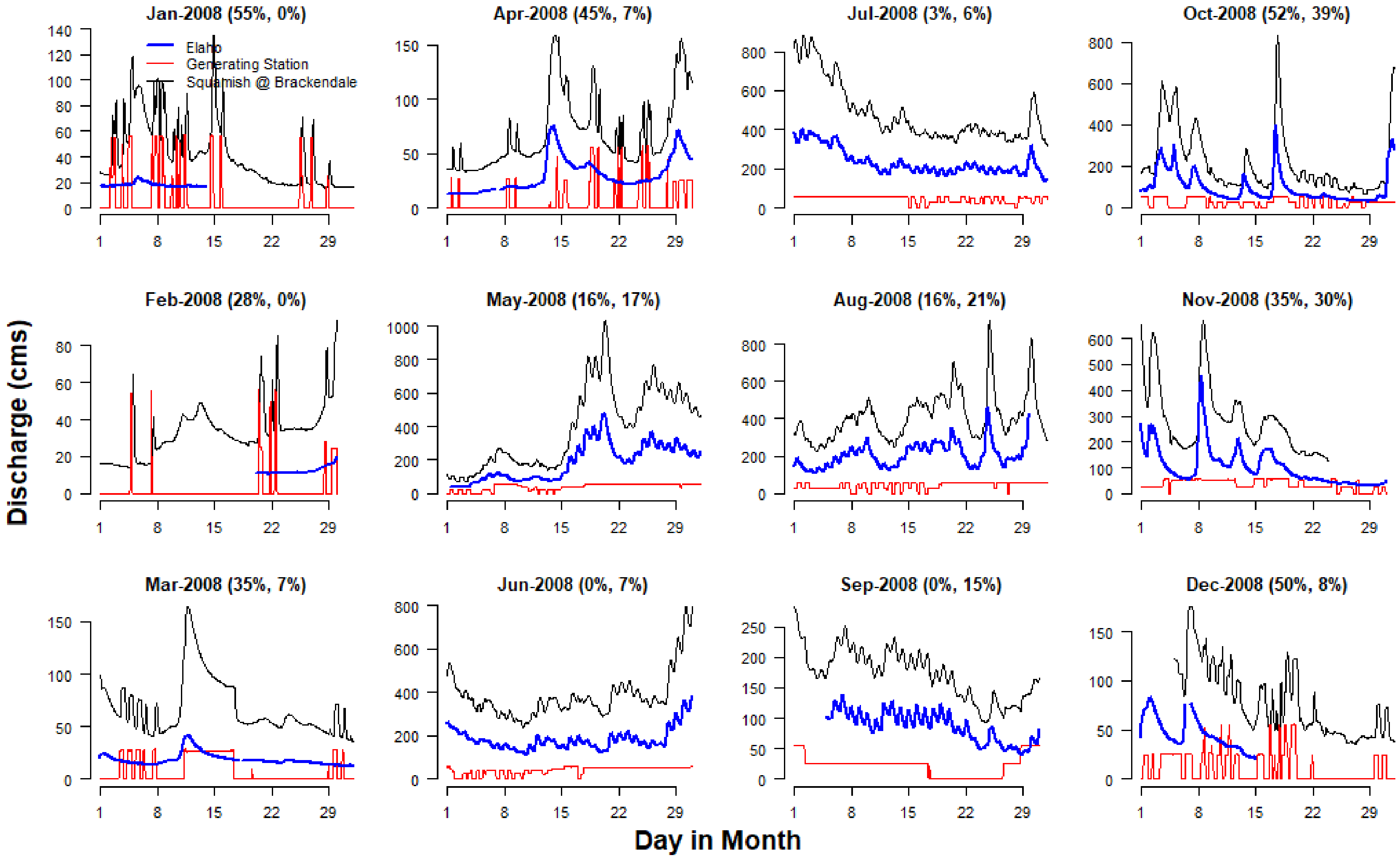


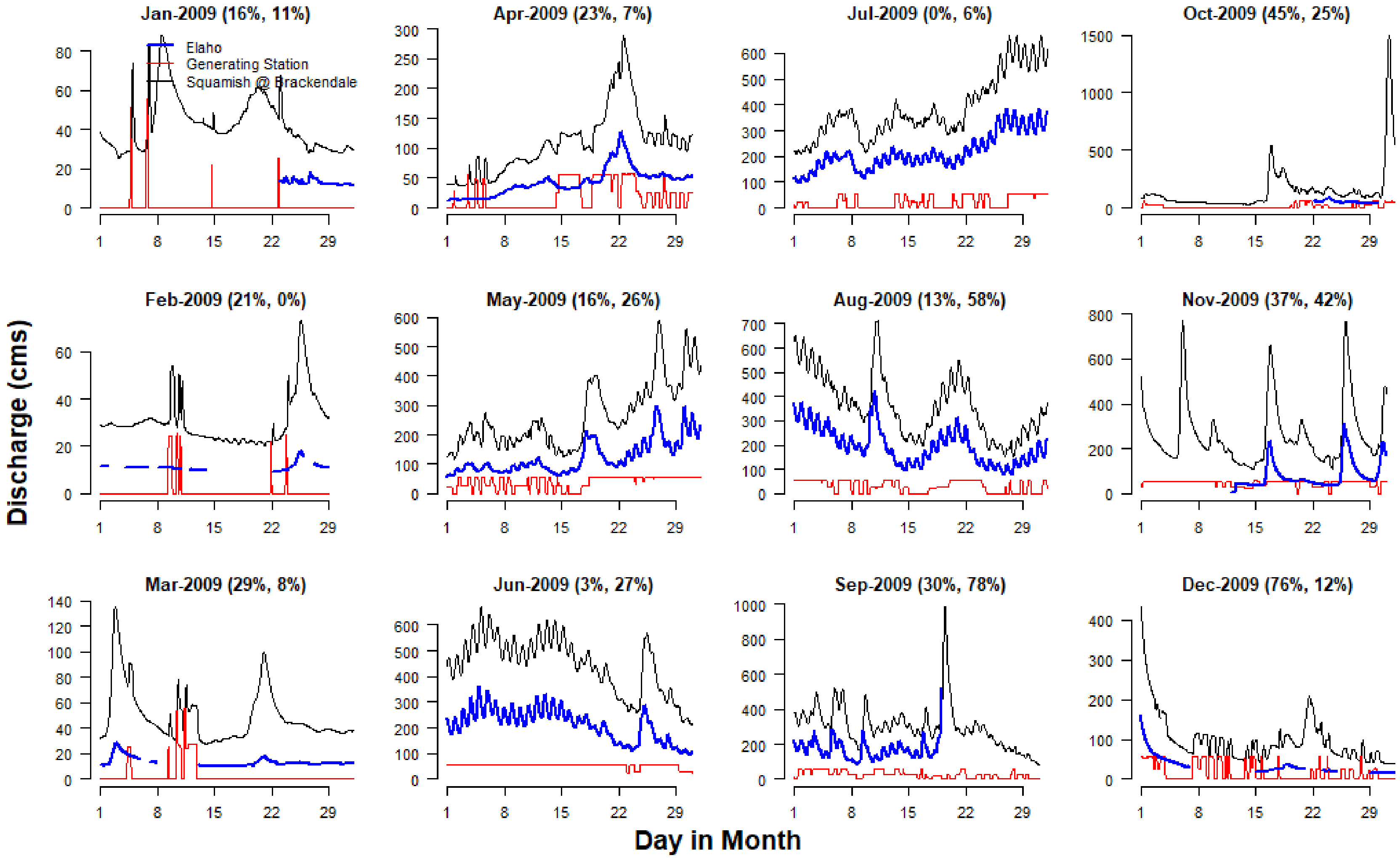
Jan-2004 (42%, 6%)
Apr-2004 (10%, 10%)
Jul-2004 (10%, 26%)
Oct-2004 (35%, 32%)
Feb-2004 (55%, 0%)
May-2004 (6%, 23%)
Aug-2004 (3%, 58%)
Nov-2004 (60%, 40%)
Mar-2004 (39%, 13%)
Jun-2004 (0%, 27%)
Sep-2004 (30%, 70%)
Dec-2004 (87%, 27%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

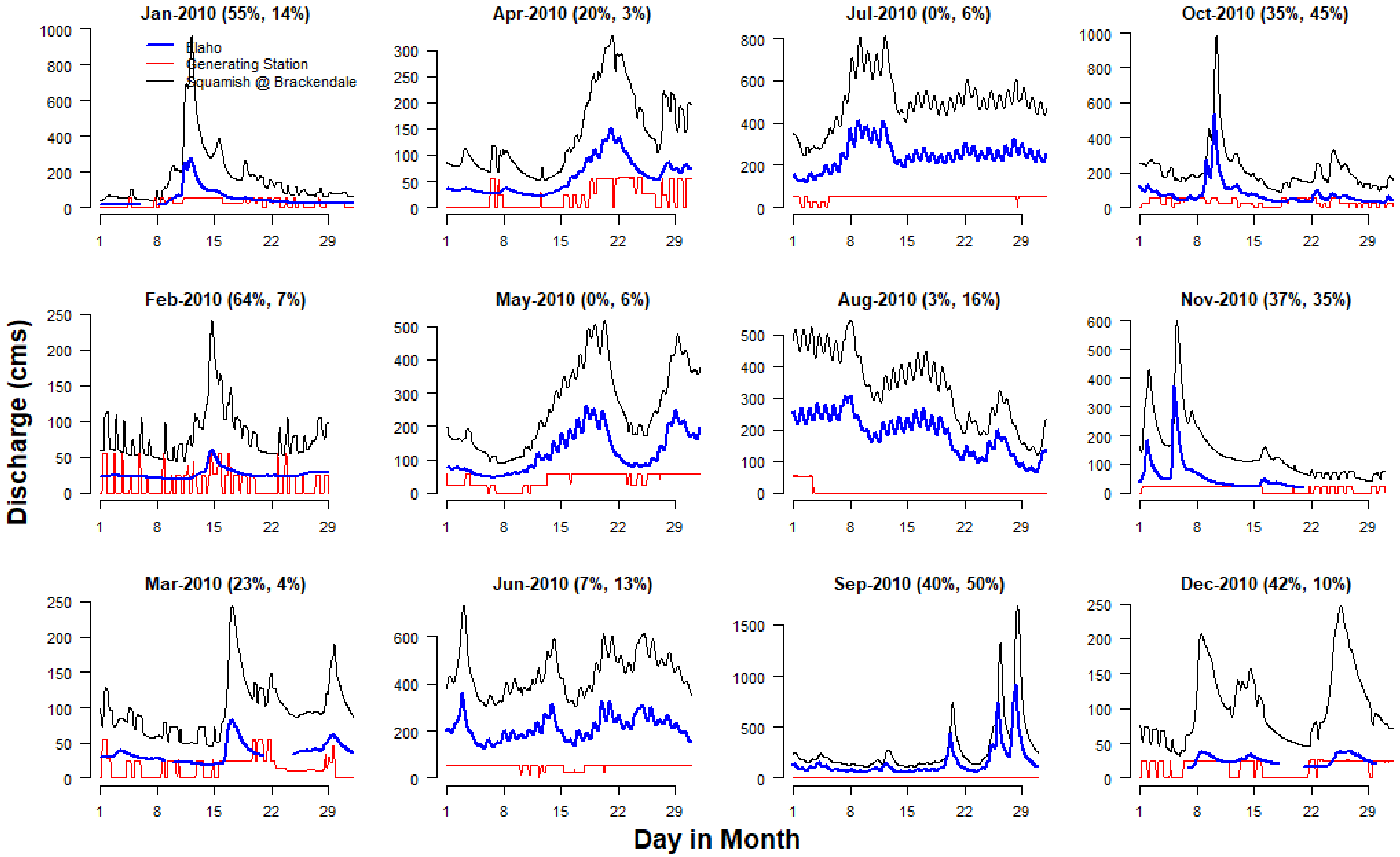

Jan-2005 (74%, 50%)
Elaho
Generating Station
Squamish @ Brackendale
0
200
400
600
800
1000
1200
Apr-2005 (20%, 30%)
0
100
200
300
400
500
Jul-2005 (13%, 29%)
0
200
400
600
800
1000
Oct-2005 (58%, 58%)
0
200
400
600
800
1000
1200
Feb-2005 (32%, 0%)
0
50
100
150
200
250
May-2005 (13%, 35%)
0
200
400
600
800
Aug-2005 (10%, 81%)
0
100
200
300
400
500
600
700
Nov-2005 (57%, 33%)
0
100
200
300
400
500
600
700
Mar-2005 (29%, 16%)
0
50
100
150
200
250
300
Jun-2005 (13%, 20%)
0
100
200
300
400
500
600
700
Sep-2005 (23%, 63%)
0
200
400
600
Dec-2005 (74%, 26%)
0
200
400
600
800
1000
1
8
15
22
29
Discharge (cms)
Day in Month

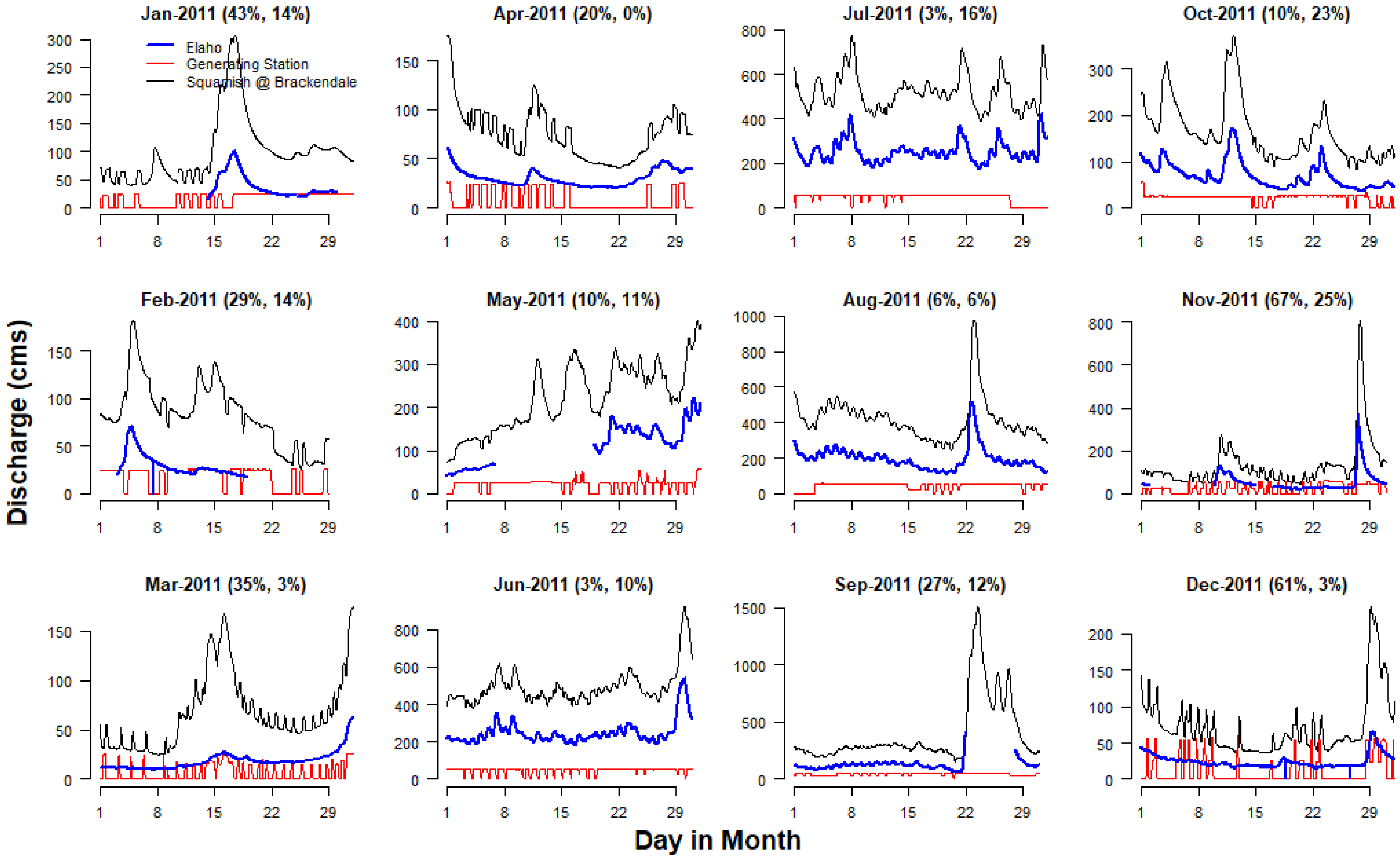

Jan-2006 (26%, 10%)
Apr-2006 (57%, 7%)
Jul-2006 (3%, 10%)
Oct-2006 (26%, 26%)
Feb-2006 (46%, 0%)
May-2006 (6%, 6%)
Aug-2006 (0%, 81%)
Nov-2006 (40%, 40%)
Mar-2006 (52%, 4%)
Jun-2006 (7%, 13%)
Sep-2006 (17%, 93%)
Dec-2006 (77%, 11%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

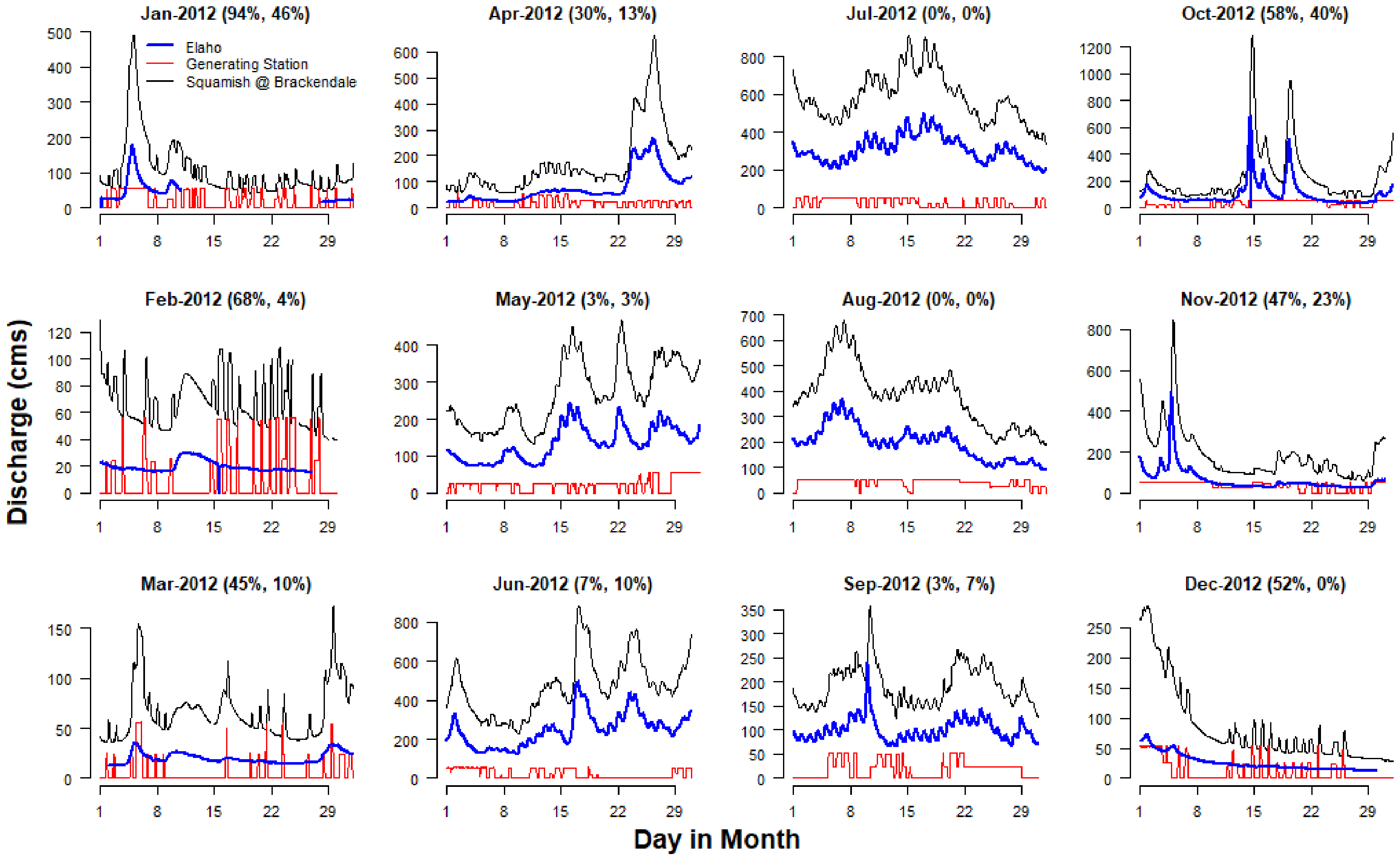

Jan-2007 (67%, 10%)
Apr-2007 (37%, 13%)
Jul-2007 (3%, 0%)
Oct-2007 (42%, 67%)
Feb-2007 (46%, 18%)
May-2007 (13%, 3%)
Aug-2007 (3%, 6%)
Nov-2007 (37%, 18%)
Mar-2007 (32%, 35%)
Jun-2007 (3%, 0%)
Sep-2007 (13%, 20%)
Dec-2007 (70%, 14%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

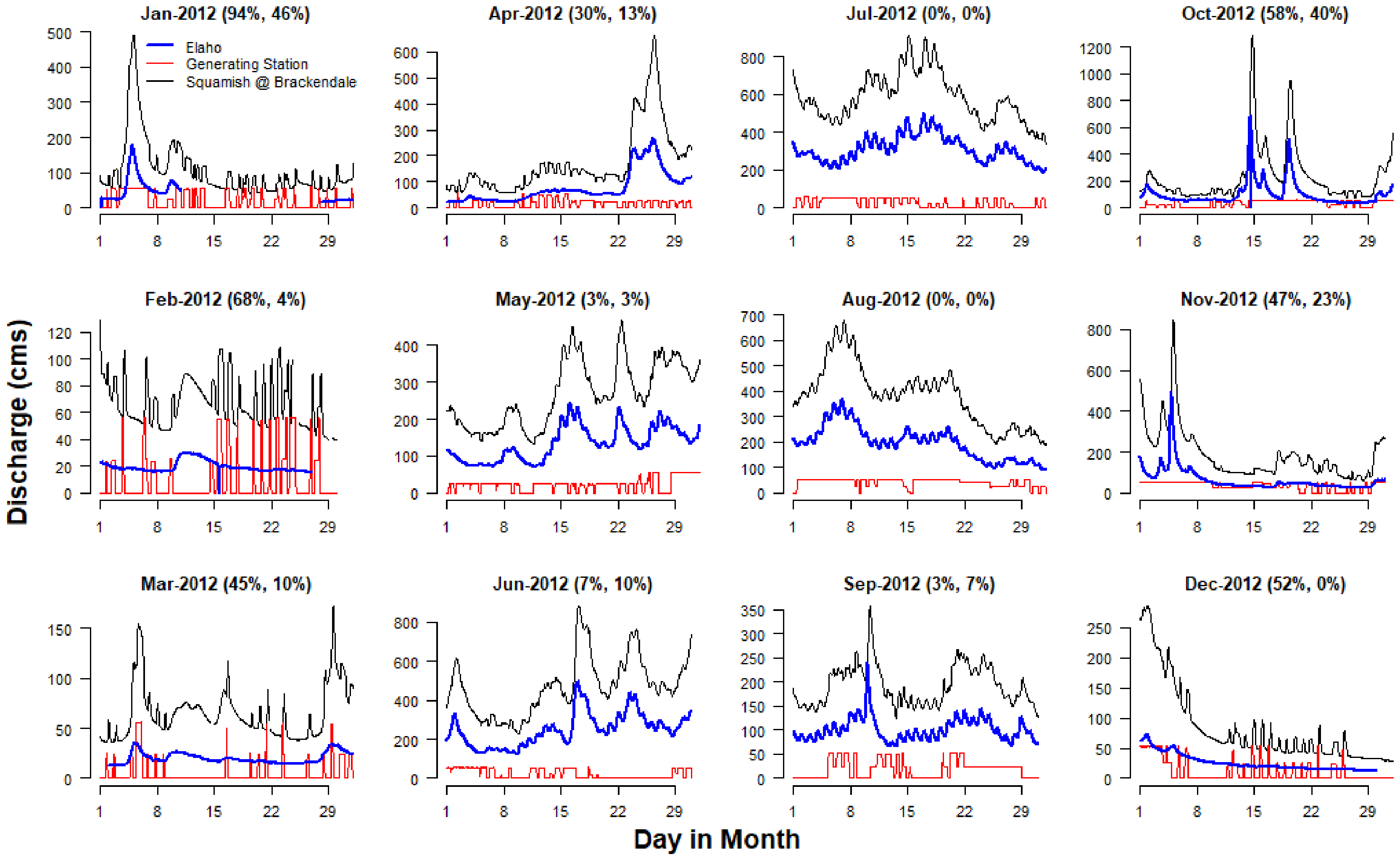

Jan-2008 (55%, 0%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-2008 (45%, 7%)
Jul-2008 (3%, 6%)
Oct-2008 (52%, 39%)
Feb-2008 (28%, 0%)
May-2008 (16%, 17%)
Aug-2008 (16%, 21%)
Nov-2008 (35%, 30%)
Mar-2008 (35%, 7%)
Jun-2008 (0%, 7%)
Sep-2008 (0%, 15%)
Dec-2008 (50%, 8%)
Discharge (cms)
Day in Month
1
8
15
22
29

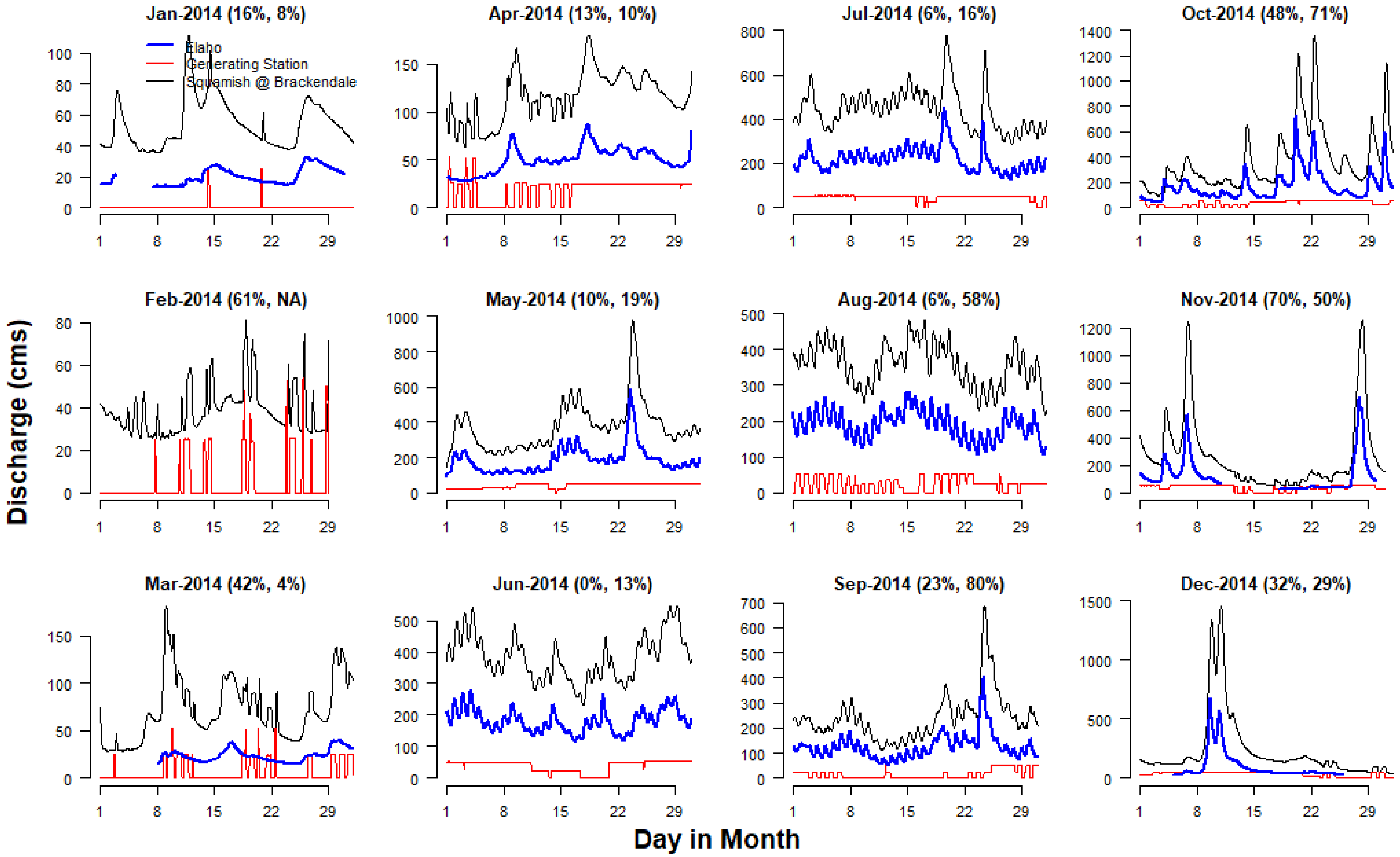

Jan-2009 (16%, 11%)
Apr-2009 (23%, 7%)
Jul-2009 (0%, 6%)
Oct-2009 (45%, 25%)
Feb-2009 (21%, 0%)
May-2009 (16%, 26%)
Aug-2009 (13%, 58%)
Nov-2009 (37%, 42%)
Mar-2009 (29%, 8%)
Jun-2009 (3%, 27%)
Sep-2009 (30%, 78%)
Dec-2009 (76%, 12%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

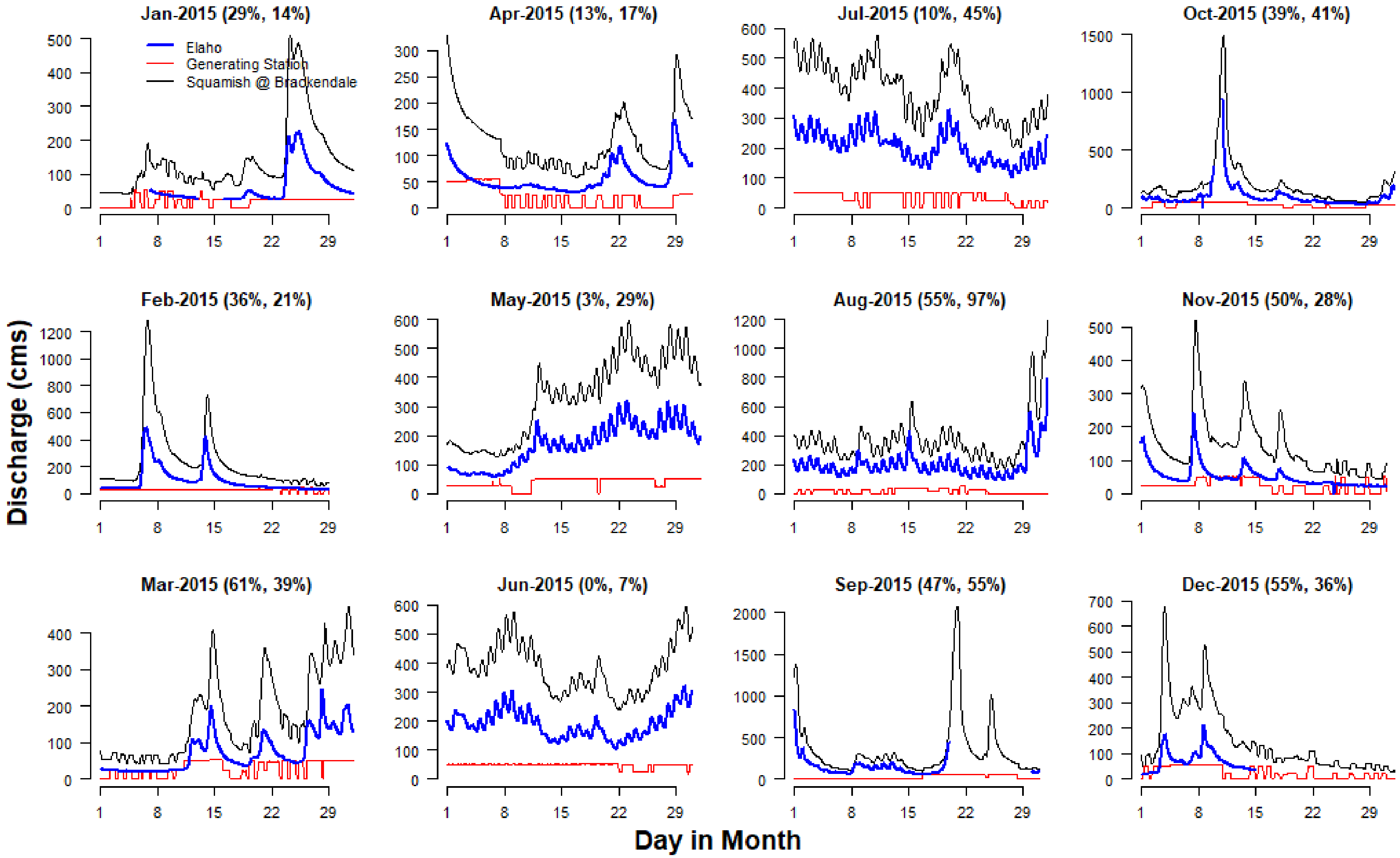

Jan-2010 (55%, 14%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-2010 (20%, 3%)
Jul-2010 (0%, 6%)
Oct-2010 (35%, 45%)
Feb-2010 (64%, 7%)
May-2010 (0%, 6%)
Aug-2010 (3%, 16%)
Nov-2010 (37%, 35%)
Mar-2010 (23%, 4%)
Jun-2010 (7%, 13%)
Sep-2010 (40%, 50%)
Dec-2010 (42%, 10%)
Discharge (cms)
Day in Month
1
8
15
22
29

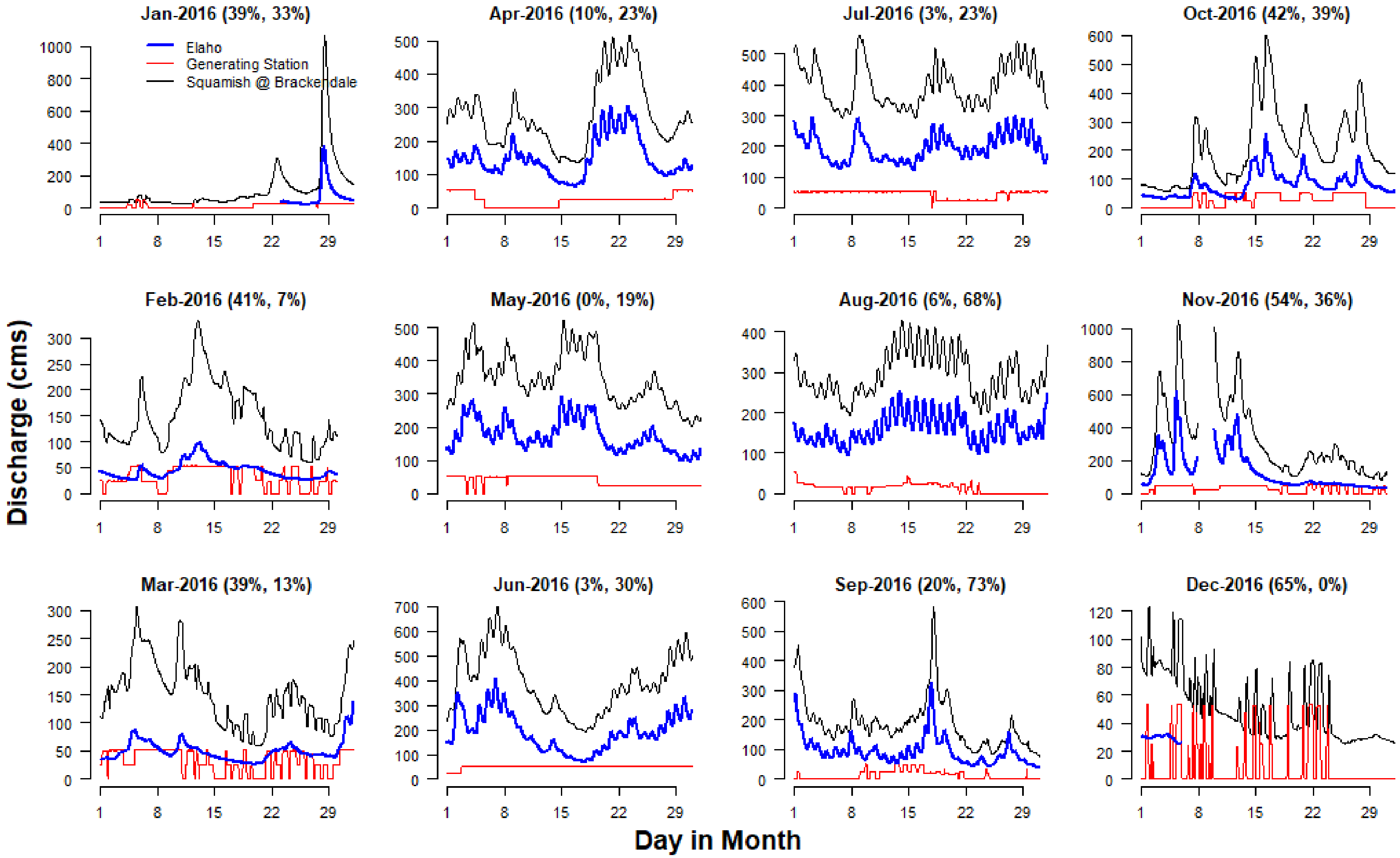

Jan-2011 (43%, 14%)
Apr-2011 (20%, 0%)
Jul-2011 (3%, 16%)
Oct-2011 (10%, 23%)
Feb-2011 (29%, 14%)
May-2011 (10%, 11%)
Aug-2011 (6%, 6%)
Nov-2011 (67%, 25%)
Mar-2011 (35%, 3%)
Jun-2011 (3%, 10%)
Sep-2011 (27%, 12%)
Dec-2011 (61%, 3%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29

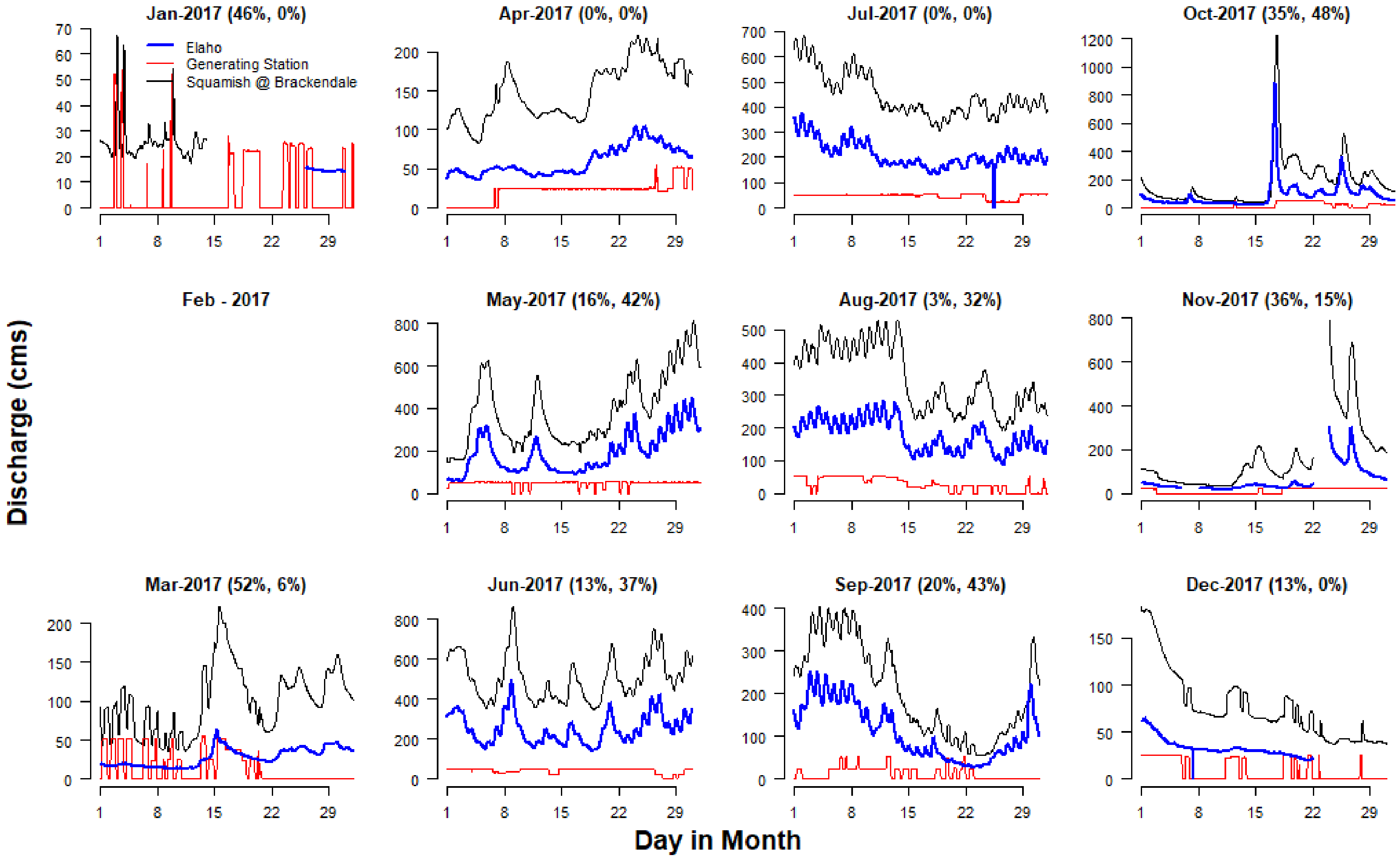

Jan-2012 (94%, 46%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-2012 (30%, 13%)
Jul-2012 (0%, 0%)
Oct-2012 (58%, 40%)
Feb-2012 (68%, 4%)
May-2012 (3%, 3%)
Aug-2012 (0%, 0%)
Nov-2012 (47%, 23%)
Mar-2012 (45%, 10%)
Jun-2012 (7%, 10%)
Sep-2012 (3%, 7%)
Dec-2012 (52%, 0%)
Discharge (cms)
Day in Month
1
8
15
22
29
0
100
200
300
400
500
600
700
800
1000
1200
20
40
60
80
120
50
150
250
350


Jan-2012 (94%, 46%)
Elaho
Generating Station
Squamish @ Brackendale
Apr-2012 (30%, 13%)
Jul-2012 (0%, 0%)
Oct-2012 (58%, 40%)
Feb-2012 (68%, 4%)
May-2012 (3%, 3%)
Aug-2012 (0%, 0%)
Nov-2012 (47%, 23%)
Mar-2012 (45%, 10%)
Jun-2012 (7%, 10%)
Sep-2012 (3%, 7%)
Dec-2012 (52%, 0%)
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-2014 (16%, 8%)
Apr-2014 (13%, 10%)
Jul-2014 (6%, 16%)
Oct-2014 (48%, 71%)
Feb-2014 (61%, NA)
May-2014 (10%, 19%)
Aug-2014 (6%, 58%)
Nov-2014 (70%, 50%)
Mar-2014 (42%, 4%)
Jun-2014 (0%, 13%)
Sep-2014 (23%, 80%)
Dec-2014 (32%, 29%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-2015 (29%, 14%)
Apr-2015 (13%, 17%)
Jul-2015 (10%, 45%)
Oct-2015 (39%, 41%)
Feb-2015 (36%, 21%)
May-2015 (3%, 29%)
Aug-2015 (55%, 97%)
Nov-2015 (50%, 28%)
Mar-2015 (61%, 39%)
Jun-2015 (0%, 7%)
Sep-2015 (47%, 55%)
Dec-2015 (55%, 36%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29


Jan-2016 (39%, 33%)
Apr-2016 (10%, 23%)
Jul-2016 (3%, 23%)
Oct-2016 (42%, 39%)
Feb-2016 (41%, 7%)
May-2016 (0%, 19%)
Aug-2016 (6%, 68%)
Nov-2016 (54%, 36%)
Mar-2016 (39%, 13%)
Jun-2016 (3%, 30%)
Sep-2016 (20%, 73%)
Dec-2016 (65%, 0%)
Elaho
Generating Station
Squamish @ Brackendale
Discharge (cms)
Day in Month
1
8
15
22
29
0
200
400
600
800
1000


Discharge (cms)
Day in Month
Elaho
Generating Station
Squamish @ Brackendale
Jan-2017 (46%, 0%)
Apr-2017 (0%, 0%)
Jul-2017 (0%, 0%)
Oct-2017 (35%, 48%)
Feb - 2017
May-2017 (16%, 42%)
Aug-2017 (3%, 32%)
Nov-2017 (36%, 15%)
Mar-2017 (52%, 6%)
Jun-2017 (13%, 37%)
Sep-2017 (20%, 43%)
Dec-2017 (13%, 0%)
0
10
20
30
40
50
60
70
50
100
150
200
100
200
300
400
500
600
700
1200
1000
800
600
400
300
1
8
15
22
29