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Analysis and Visualization of Streamflow Timing Trends and Changes in Snowmelt Domination in Western North America

by

Holger Fritze

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Declaration of Authorship

I, Holger Fritze, declare that this thesis titled, 'Analysis and Visualization of Streamflow Timing Trends and Changes in Snowmelt Domination in Western North America' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Abstract

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Snowmelt derived water is of great importance for most streams across Western North America. A changing climate affects streamflow and changes its intraannual contribution. Shifts of the center of timing (CT) and the start of snowmelt pulse towards earlier in the year have already been detected for the 1948-2000 period. While the trends for CT have increased for the 1948-2008 period, the ones for the snowmelt pulse did not appear to have accelerated. In contrast the number of snowmelt pulses decreased within the same period and indicated that more winter precipitation came as rain rather than snow. Based on the ratio of years with and without snowmelt pulses this study has developed a measure of snowmelt domination and classified the streams into four categories. These categories were used to compare groups of streams with similar runoff characteristics and to quantify shifts in snowmelt domination regimes. Furthermore the data and measures were interactively visualized on a virtual globe using Nasa World Wind Java.

Acknowledgements

This work would not have been possible without the support of many people, whom I sincerely would like to thank.

First of all I am deeply grateful to my both advisors Prof. Iris Stewart-Frey and Prof. Edzer Pebesma for offering me such an interesting topic of investigation. Iris Stewart-Frey deserves special thanks for the critics and the always precise comments, which made an extensive contribution to this work. Our collaboration was really an inspiring experience. Thank you very much. Edzer Pebesma had a very significant influence on me from the first time we met. His encouragement and motivational strength as well as working in his research group let me discover a broad field of interests and is of immeasurable value.

My special thank goes to Mary Tyree from Scripps Institution of Oceanography for providing river discharge data for the Canadian streams.

Furthermore, I would like to thank my friends Thore, Miranda, Elizabeth and Kristina for their advices and help and especially my friend Anja for her understanding and tsupport.

I want to dedicate this work to my beloved parents, who always believed in me and helped me with moral and financial support throughout my studies. I owe you everything.

Holger Fritze

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Abbreviations

CT	Center of Timing, *also Center of Mass*
HCDN	Hydro-Climatic Data Network
Jisao	Joint Institute for the Study of the Ocean and the Atmosphere
JRE	Java Runtime Environment
NCRS	Natural Resources Conservation Service
NOAA	National Oceanic and Atmospheric Administration
NWCC	National Water and Climate Center
NWIS	National Water Information System
PDO	Pacifc Decadal Oscillation
PI	Precipitation Index
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SDC	Snowmelt Domination Category
SST	Sea Surface Temperature
TI	Temperature Index
USGS	U.S. Geological Survey
VG	Virtual globe
WWJ	Nasa World Wind Java SDK

Chapter 1

Introduction

In the Western North America, mountain snowmelt runoff contributes a great fraction to annual streamflow and can be quantified to about 75% (Dettinger, 2005, Stewart et al., 2004). It is an important component for ecosystems, agriculture and urban water supplies. Streamflow timing is as important as quantity and quality (Dettinger and Cayan, 1995) and effects of climate change and associated temperature and precipitation shifts are of great concern in the western North America. Especially in the dry Southwest the situation has exacerbated within the last decade (Anderson et al., 2008). The risk of droughts increased, which in turn affected the urban water supplies because water reservoir were got historic lows. Previous works have documented shifts towards earlier streamflow timing over the past few decades (Cayan et al., 2001b, Dettinger, 2005, Knowles et al., 2006, McCabe and Clark, 2005, Stewart et al., 2005). This study sought to investigate whether these trends had continued or even increased within the last decade. The past years have seen some of the hottest years on record (Bates et al., 2008) and last year California experienced the driest spring and summer on record (NOAA, 2009). This study applied analyses to both snowmelt dominated and rain dominated streams and classified the streams into categories (chapter 3.2). Trend analyses have compared trends in CT and snowmelt pulse for the 1947-2000 period with the ones for the 1947-2008 period (chapter 4.1). The categories were used as classification tool but were also analyzed towards changes in regime domination (chapter 4.3). A last focus was on an exploration of visualization techniques to present the data, measures and results (chapter 5). An application using a virtual globe was implemented and provides a collection of the graphical outcome of this work.

Chapter 2

Data

The data in this study were provided by the USGS, the PRISM Group, Environment Canada and JISAO and could be mostly downloaded from websites and interfaces. The data is used for the 1948-2008 period and the Western North American continent North of 29° and West of $-105°$ and includes the US states Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming and the Canadian provinces Alberta, British Columbia, Northwest Territories, Saskatchewan and Yukon Territory. A table containing a summary of the source's metadata can be found in table 2.1 (page 5).

2.1 Stream Discharge

Sream discharge is defined "as the volume rate of flow of the water in the channel, including any sediment or other solids that may be dissolved or mixed with it. Dimensions are usually expressed in cubic feet [or meter] per second. Other common units are million gallons per day and acre-feet per day" (Buchanan and Somers, 1976). The selection of the stream gauges was based on the USGS Hydro-Climatic Data Network (HCDN) (Slack and Landwehr, 1992). This data set represents a collection of streams which are regarded to be mostly free of anthropogenic influences and have a natural runoff behavior over the whole observational period. Therefore these streams allow a study of climatic change over hydrologic basins (Vogel and Sankarasubramanian, 2005). The water data for the United States is provided by the USGS National Water Information Service (NWIS) (http://waterdata.usgs.gov/nwis/sw). The water data for Canada was provided by Environment Canada and through Scripps Institution of Oceanography. The selection of these gauges was based on the availability of sufficient data. Streams were discarded from the analysis presented here, if their data sets had less than 40 years of full records. A list of the 309 US and 53 Canadian gauges included in this study can be found in table A.2 (page 41). This list contains snowmelt as well as non-snowmelt dominated streams and elevation levels range from sea level at the Pacific coastlines to high altitudes in the Rocky Mountains. Note that all statements of elevation refer to the gauge's and not to the watershed's altitude, which lies above the gauge.

Throughout the whole study, the river discharge was analyzed in the dimension $\frac{m^3}{s}$ and on the annual scale of water year, which is a 12 month period, that starts at the end of the dry season on October 1^{st} and ends on September 30^{th} (compare USGS).

2.2 Political Maps and DEM

The political boundaries of the states in the US are provided by the US Census Bureau and were downloaded as shapefile from `www.census.gov/cgi-bin/geo/shapefiles/national-files`. The ones for Canada are provided by Statistics Canada and were downloaded also as shapefile from `www.statcan.gc.ca`. For the DEM the GTOPO30 was used. The global dataset is provided by USGS Center for Earth Resources Observation and Science (EROS) (`http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html`) and has a horizontal and vertical resolution of 30 arc seconds (approximately 1 kilometer).

2.3 Climate Data

Temperature and Precipitation

These analyses used time series of climate dataset from the PRISM climate group at Oregon State University and can by accessed via `ftp://prism.oregonstate.edu/pub/prism`. This dataset is a high-quality, topographically-sensitive, 2.5 min (4-km) climate data grid which uses a combined statistical and geographic approach to map climate. Climate point data from measurement stations, a DEM and other spatial data sets are used to generate a high resolution grid of climate data. PRISM (Parameter-elevation Regressions on Independent Slopes Model) uses a "coordinated set of rules, decisions, and calculations, designed to accommodate the decision-making process" (Daly and Johnson, 1998) instead of a static set of equations. The extend of the grid was limited to the USA without Alaska. Grid tiles containing a gauge were extracted and monthly averages for temperature and monthly sums for precipitation were used for calculation temperature and precipitation index.

PDO

The PDO is a measure of Northern Pacific sea surface temperature (SST) and is described as a deviation of the monthly average temperatures from the longterm historical average by using grids poleward of 20°N (Hare and Mantua, 2001). The data were provided by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and downloaded from `http://jisao.washington.edu/pdo/PDO.latest`.

Data	Data Source	Retrieval Date	Spatial Extend	Spatial Resolution	Time Period	Temporal Resolution
Stream Discharge	USA: USGS, NWIS Canada: Environment Canada processed by Scripps Institute of Oceanography	2009-03-21 2009-07-21	$-170°$W – $-105°$W 31°N – 70°N	point data measured at individual gauges USA: 309 Canada: 53	wateryear 1948 - 2008	daily averages
Temperature & Precipitation	PRISM	2009-03-27	tile at each river gauge	tile size 2.5”	wateryear 1948 - 2008	temperature: monthly averages precipitation: monthly sums
PDO	University of Washington	2007-05-07	North Pacific Ocean (North of 20°)	N/A	1948-2008	monthly averages
political maps	US Census Bureau	2009-03-22	States of the US: AK, AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY Provinces in CA: ALB, BCL, NTR, SSK, YTR	N/A	N/A	N/A
DEM	USGS, GTOPO30	2009-07-20	100°W - 180°W 90°W - 40°W ——— 100°W - 140°W 90°W - 10°W	tile size 30 Arc Seconds	developed over a three year period	completed in 1996

Table 2.1 Data Sources

Chapter 3

Methodology

3.1 Streamflow Timing Measures

Changes in streamflow timing can and have been described in various ways, depending on the data availability and purpose of the analysis (compare Dettinger (2005)). In this study several already existing measures were used and applied to the most recent data. In addition some streamflow timing assessments were also improved and extended. Note, that this study focused only on the timing aspect, there was no comparison of streamflow volume between different gauges.

3.1.1 Fraction of Annual Streamflow

Roos (1991) and Dettinger and Cayan (1995) as well as Aguado et al. (1992) and Stewart et al. (2005) have used monthly fractional runoff hydrographs for individual streams with different altitudes. Monthly fraction of the annual runoff smoothes the variability of daily data by introducing an abstraction layer. This study used this measure not for single streams but for a collection of streams and has applied it to the Snowmelt Domination Categories (see chapter 3.2). Trend analysis was used to investigate in changes for monthly flow fractions (see chapter 4.3).

3.1.2 Start of the Snowmelt Runoff Pulse

Cayan et al. (2001b) developed an algorithm to detect the change from low winter base flow to high spring flow conditions by a combination of finding the day when the cumulated departure from the year's mean flow is most negative and some additional criteria. The algorithm, illustrated in Fig. 3.1 does not take the whole year into account, but only the first eight months of the water year, because the summer month streamflow has no effect on the start of the snowmelt runoff pulse for the mid-latitudes and mid-to-high elevation watersheds. As this study also incorporated non-snowmelt dominated gauges as well as snowmelt-regime shifts (see chapter 4.3) an adaptation of the snowmelt pulse algorithm was necessary to avoid finding a snowmelt pulse for rain dominated years. The two criteria are:

- a snowmelt pulse can only occur between the 174th and 250th day since beginning of water year (between Mar 23rd and June 5th)
- rain dominated stream create positive and negative departures from the year's mean flow. A snowmelt pulse was logically excluded if the ratio positive to negative area was greater than one

The start of the snowmelt runoff pulse is often not as clearly defined as the one in Fig. 3.1 (a). Therefore this measure is characterized by a high year-to-year variability which is not only caused by climate variability.

The algorithm was one of the major parts of this study and was used for categorizing the streams by the Snowmelt Domination Categories (see section 3.2).

3.1.3 Center of Mass

Stewart et al. (2004) characterized the discharge by the "center of mass" (CT) which is a robust timing measure representing the day of the year by which half of the annual runoff has passed. This flow weighted timing measure is calculated as

$$\mathrm{CT} = \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{t_i q_i})}{\sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{q_i})}$$

with t_i the time in days from beginning of the water year and q_i the corresponding discharge for day i.A late CT indicates a lower winter and a higher spring discharge (and a tendency towards greater snow domination), while an early CT is an indication of a higher winter precipitation as rain.

The two timing measures, CT and snowmelt runoff pulse algorithm, were calculated for each gauge and year and an example is illustrated in Fig. 3.2. It shows the daily streamflow measurements, the average streamflow of the year and the average streamflow of the gauge. The CT is represented by a vertical red line and the start of the snowmelt runoff pulse by a red star. Graphics for each gauge and year can be found in the application (compare chapter 5, page 28).

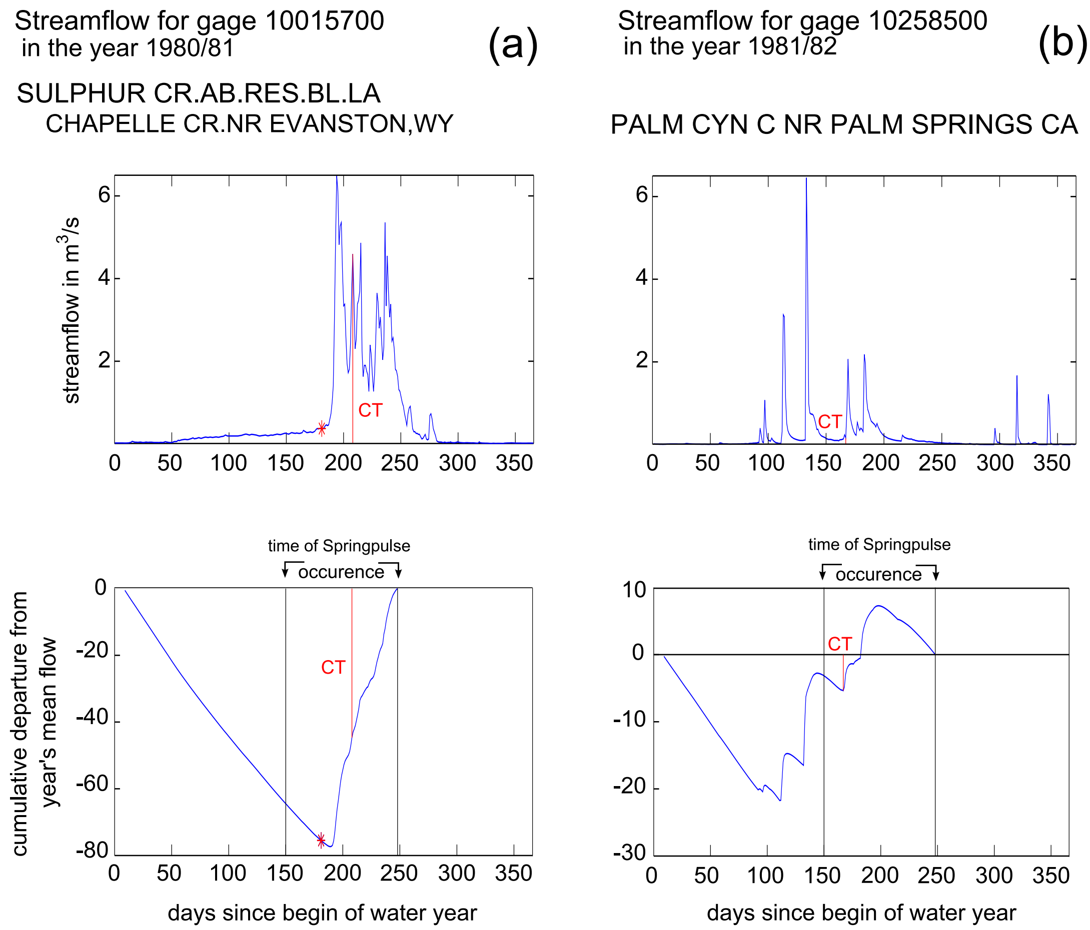


FIGURE 3.1 Comparison of hydrographs and their corresponding cumulated departures used by the snowmelt pulse algorithm for a snowmelt dominated stream (a) and a non snowmelt dominated stream (b). The hydrographs and the graphs of the cumulated departure look completely different. Whereas the snowmelt dominated stream on the left has one global minimum the rain dominated stream on the right has several local minima and even a global maximum.

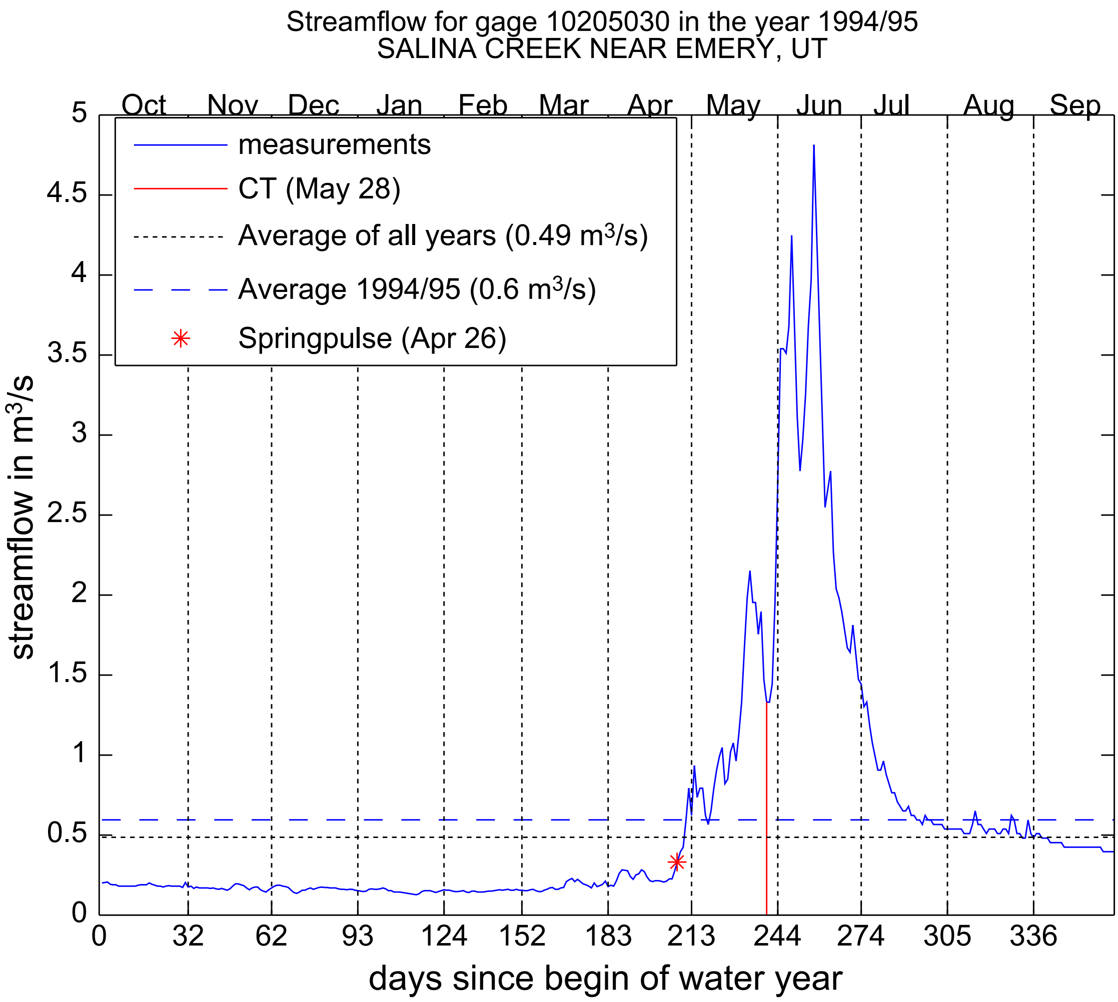


FIGURE 3.2 Hydrograph of the 1994/95 discharge of the Salina Creak, Utah, USGS Gauge 10205030

3.2 Snowmelt Domination Categories

Based on the snowmelt pulse algorithm (see Chapter 3.1.2) and the ratio between years with and without a snowmelt pulse a new measure of stream categorization was introduced, which assigns streams to categories by the number of denoted snowmelt pulses. The Snowmelt Domination Categories (SDC) are a measure of similarity in runoff behavior and defines as:

SDC 1: **clearly rain dominated**
: a snowmelt pulse occurred in less than 30% of the years

SDC 2: **mostly rain dominated**
: a snowmelt pulse occurred in more than 30% and less than 50% of the years

SDC 3: **mostly snowmelt dominated**
: a snowmelt pulse occurred in more than 50% and less than 70% of the years

SDC 4: **clearly snowmelt dominated**
: a snowmelt pulse occurred in more than 70% of the years

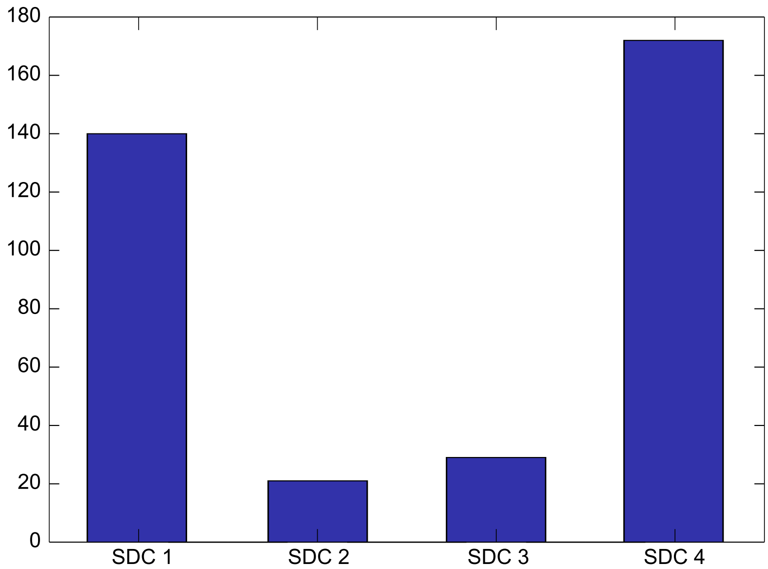


FIGURE 3.3 Number of streams for each Snowmelt Domination Category (SDC) for the 1948-2008 observation period

The bar chart in figure 3.3 illustrates that the clearly snowmelt or rain dominated categories contain streams (SDC 1 140 gauges, SDC 4 172 gauges), whereas the intermediate categories contain much less gauges (SDC 2 21 gauges, SDC 3 29 gauges). The map in figure 3.4 shows a dependency on the location in the graticule as well as on the elevation. The higher the latitude and the altitude the higher is the ratio of snowmelt pulses and thus the Snowmelt Domination Category.

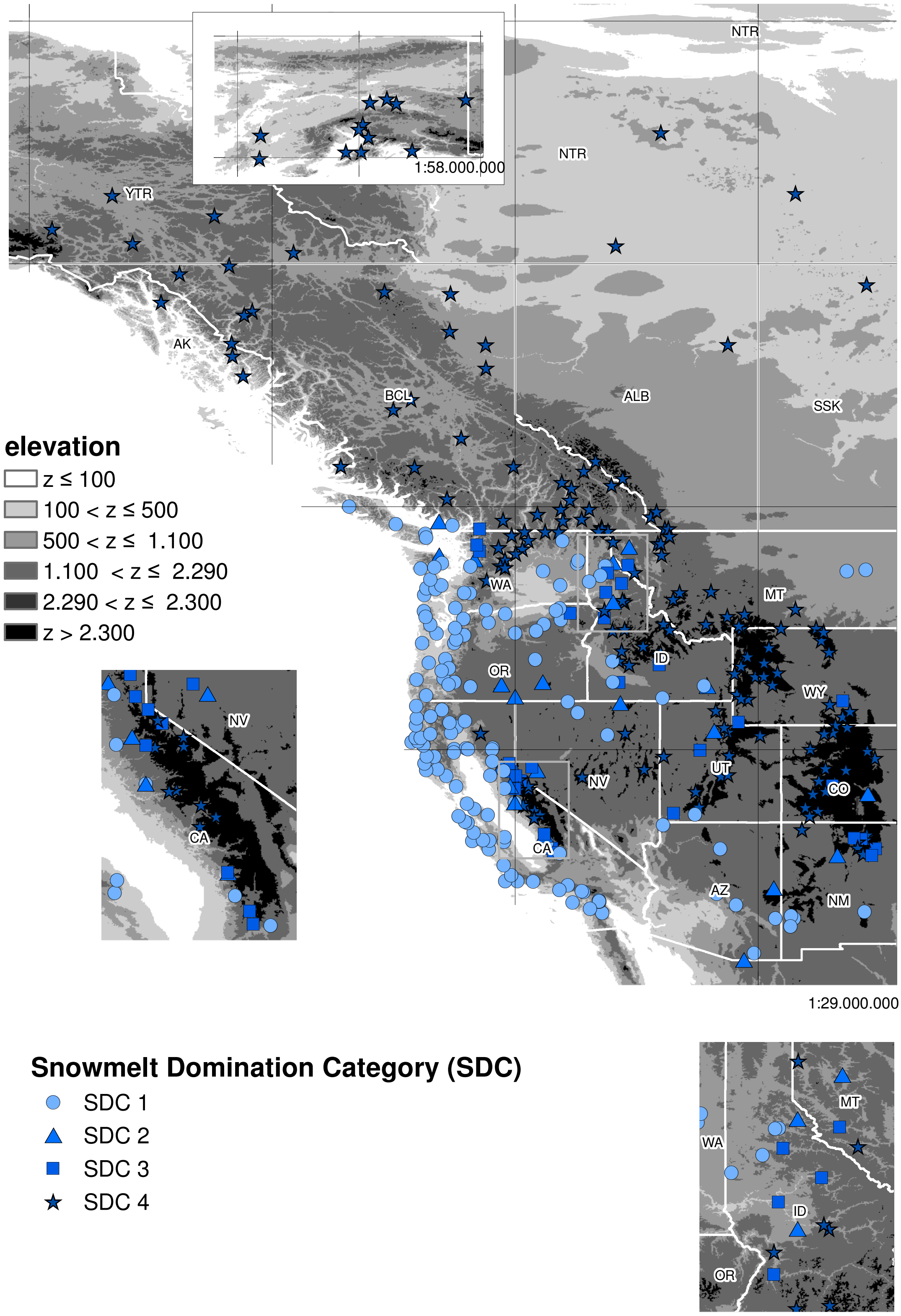


FIGURE 3.4 Gauge locations with denoted Snowmelt Domination Category (SDC)

3.3 Connection to Temperature and Precipitation

A gauge's CT and snowmelt pulse are affected by temperature as well as precipitation, which reflect the climatic conditions (Stewart et al., 2004). The influence of precipitation on streamflow timing is quantified through a precipitation index (PI), which describes the anomaly of a year's October to January average in precipitation to the average of the observational period and was calculated by:

$$PI_i = P_i - \bar{P}$$

with

PI_i the gauge specific precipitation index for year i ($1948 \leq i \leq 2008$)

P_i the average for precipitation in the months October, November, December and January of year i ($1948 \leq i \leq 2008$)

$\bar{P}$ the average precipitation in the months October, November, December and January for the 1948 - 2008 period

Similarly a temperature index (TI) was calculated for each gage. The TI represents the temperature anomaly for a gage specific four-month period, which includes the month of average CT, the two months prior and the one after the CT.

$$TI_i = T_i - \bar{T}$$

with

TI_i the gauge specific temperature index for year i ($1948 \leq i \leq 2008$)

T_i the average temperature of the gage specific four-month period based on the average CT over all years

$\bar{T}$ the average temperature over the four-month periods for the years 1948 - 2008

An index of zero indicates a temperature/precipitation equal to the longterm average. The index is negative for cooler/dryer years and positive for hotter/wetter years. The higher the anomaly the more severe is the year's situation.

3.4 Correlation to PDO

Several studies have also documented a strong correlation between streamflow and the Pacific Decadal Oscillation (Mantua et al., 1997, Nigam et al., 1999). In this context the influence on the variability of CT and the snowmelt pulse is of special interest for this study and an interesting question is how much of the year-to-year variability in streamflow can be described to influences of the PDO and how much to other climatic variations. Mapping of the PDO the correlation between the PDO index and both streamflow timing measures will yield a spatial description of the strength of the influence of the PDO on streamflow timing throughout the domain.

3.5 Trend Analysis

Quantifying the changes over time for all timing measures (CT, snowmelt pulse, fraction of annual Streamflow) was achieved by linear regression analysis. The data (Y) were fitted to the time (X) according to the linear function $Y = aX+b+\epsilon$, where a is the slope and b is the ordinate intercept, by minimizing the error terms $\epsilon = y_i - y_i^*$ using linear least squares. Matlab's *robustfit*-function performing the linear regression was able to handle *NaN*s by treating them as missing values and removing them from calculation. To avoid distortions in the results through too many missing values the number of NaN values must not exceed a manually defined limit of 20 percent throughout the whole study.

Chapter 4

Results

4.1 Trend Analysis

Stewart et al. (2004, 2005) illustrated that "many streams have yielded CT advances of 10-30 days over the 1948-2000 observational period". Considering the average CT shift for all gauges and the period used by Stewart et al. (2005), CT shifted on an average of 4.8 days towards earlier in that period. By extrapolating the linear regression line to include the 2001-2008 period the CT would have shifted 5.5 days earlier, but in fact linear regression for the 1948-2008 observational period showed a CT shift of 6.2 days towards earlier in the year. Thus there is some indication that streamflow timing changes overall have accelerated. The shifts for each Snowmelt Domination Category followed an ascending order. The higher the category the bigger the shifts in CT (compare figure 4.1). SDC 4 showed a shift of 8.4 days, SDC 3 of 8.1 days, SDC 2 of 6.9 days and SDC 1 of 3.1 days towards earlier in the year. The shifts were statistically significant at the 5% level throughout the whole period for SDC 4 and significant for SDC 1 and SDC 2 at the 10% level for comparing the 1948-1978 to 1979-2008 periods. The trends in CT have increased escpecially for the clearly snowmelt dominated streams.

Trends for the snowmelt pulse showed another structure. The average trends for all gauges for the 1948-2000 period (6.7 days earlier) and for the 1948-2008 period (6.5 days earlier) show almost the same shifts. While the trends taken together over the whole study area do not appear to have accelerated, the number of occurring snowmelt pulses had changed. In the the prior period the streams had in average a snowmelt pulse in 55.59% of the years, but in the later period it was only 52.10%. Linear regression showed a decrease of 9.7% of snowmelt pulse over the 1948-2008 period. The shifts in the snowmelt pulses are statistically significant at a 10% significance level for SDC 4 for the 1947-1977 to 1978-2008 periods and for the 1947-1987 to 1988-2008 periods. Tests

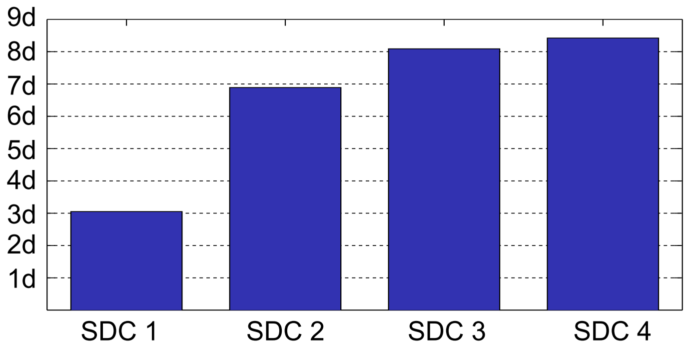


FIGURE 4.1 Shifts in CT towards earlier in the year for the 1948-2008 period in days

in significance for the lower categories as well as linear trends were not performed due to lack of data, as the occurences of snowmelt pulse define the Snowmelt Domination Categories and the lower categories have a lower ratio of snowmelt pulses.

Chapter 5 explains an application that enables quick visualization of the linear trends in CT and the snowmelt pulse for each gauge during the study period.

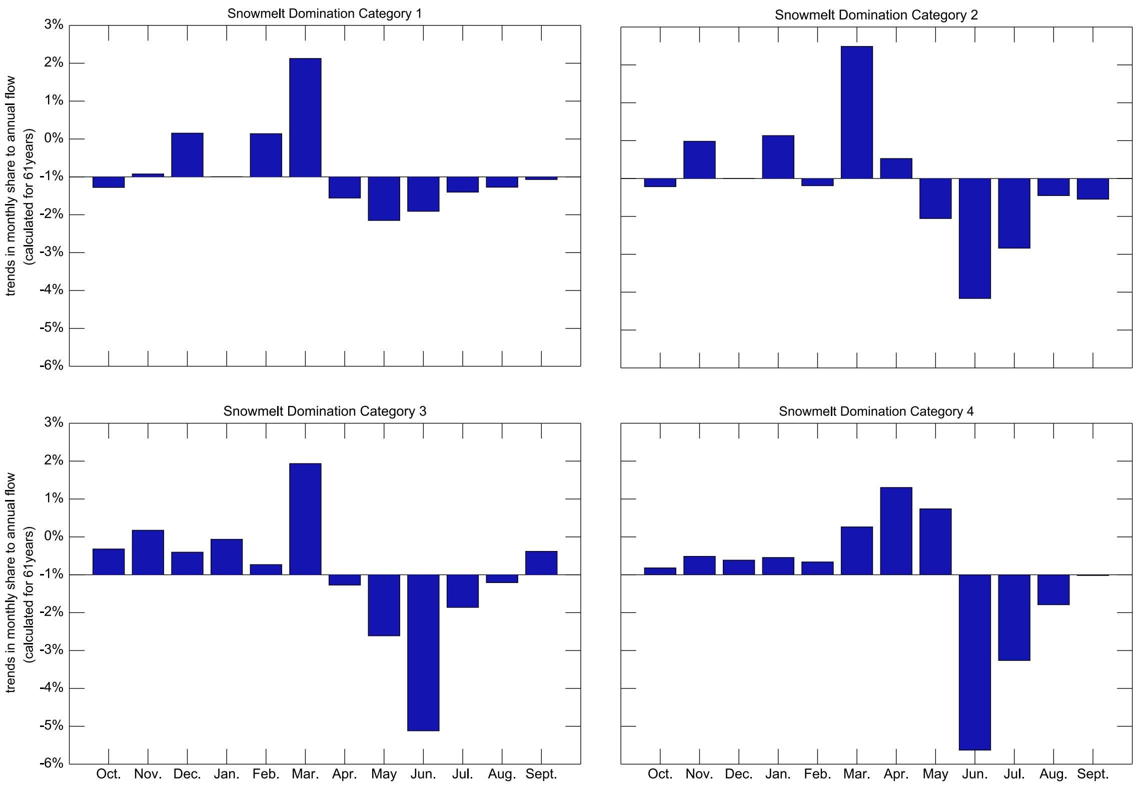


FIGURE 4.2 linear Regression for Fraction of Annual Streamflow for the 1948-2008 period

Linear regression was also applied to the monthly fraction of annual runoff and the changes for the 1948-2008 period, illustrated in Fig. 4.2, were classified by the 4 Snowmelt Domination Categories. All categories in common is an increase in the fraction of monthly to annual streamflow in the winter and early spring months and a decrease in the later months. A positive trend for the winter months indicates more precipitation as rain rather than snow. The snowmelt dominated categories (SDC 3 and 4) experienced somewhat higher changes especially in reduced flow in late spring and early summer. SDC 4, mostly comprised of watersheds at more Northern latitudes and higher altitudes, experienced shifts from June, July and August to May and June, while the shifts in the lower categories were more to March and April.

4.2 Connection to Climatic Indices

In temporal terms streamflow of snowmelt dominated streams is positively correlated to the temperature, whereas streamflow of rain dominated is directly linked to precipitation. This general difference was also evident in the relationships between the two measures CT and snowmelt pulse and the temperature and precipitation indices. For all of the four relationships the correlation coefficient ρ was used and correlation maps were created. As the data (see chapter 2.3 was only available for the US without Alaska the maps also show only that section.

In fig. 4.3 the correlation between Center of Timing (CT) and Temperature Index (TI) is mapped. When the correlation is negative temperatures are connected to an earlier CT. This is more evident for snow dominated streams than for rain dominated streams, although both categories of streams exhibit a mostly negative correlation with temperature, albeit for different reasons. As would be expected, all streams in SDC 4 but 1 had a negative correlation and the majority was between -0.33 and -0.66. Spatially the stream's correlations were linked to the elevation. The higher the elevation of the gauge the more is the CT connected with the TI ($\rho = -0.45$). SDC 1 spread over more correlation categories. Most streams were in the range of 0 and -0.33 (as warmer and drier years are connected to an earlier CT)and also lots of streams had a positive correlation. With very few exceptions streams, where CT was positively correlated with TI, were rain-dominated streams along the Pacific Coast or the Southern AZ and NM borders, that are under the influence of the summer monsoon. For those gauges the average CT occurs in the late winter months and therefore warmer moister winters for these gauges are positively related to CT.The two intermediate categories of mixed domination, SDC 2 and 3, reflected the transition between the clear snowmelt and non-snowmelt dominated streams.

The correlations between CT and Precipitation Index (PI) in Fig 4.4 show the opposite situation. In SDC 1 most streams have a correlation between -0.33 and -0.66 and some of streams had an even stronger negative correlation, thus wetter winters lead to generally later CTs for this category. On the other side the streams in SDC 4 the

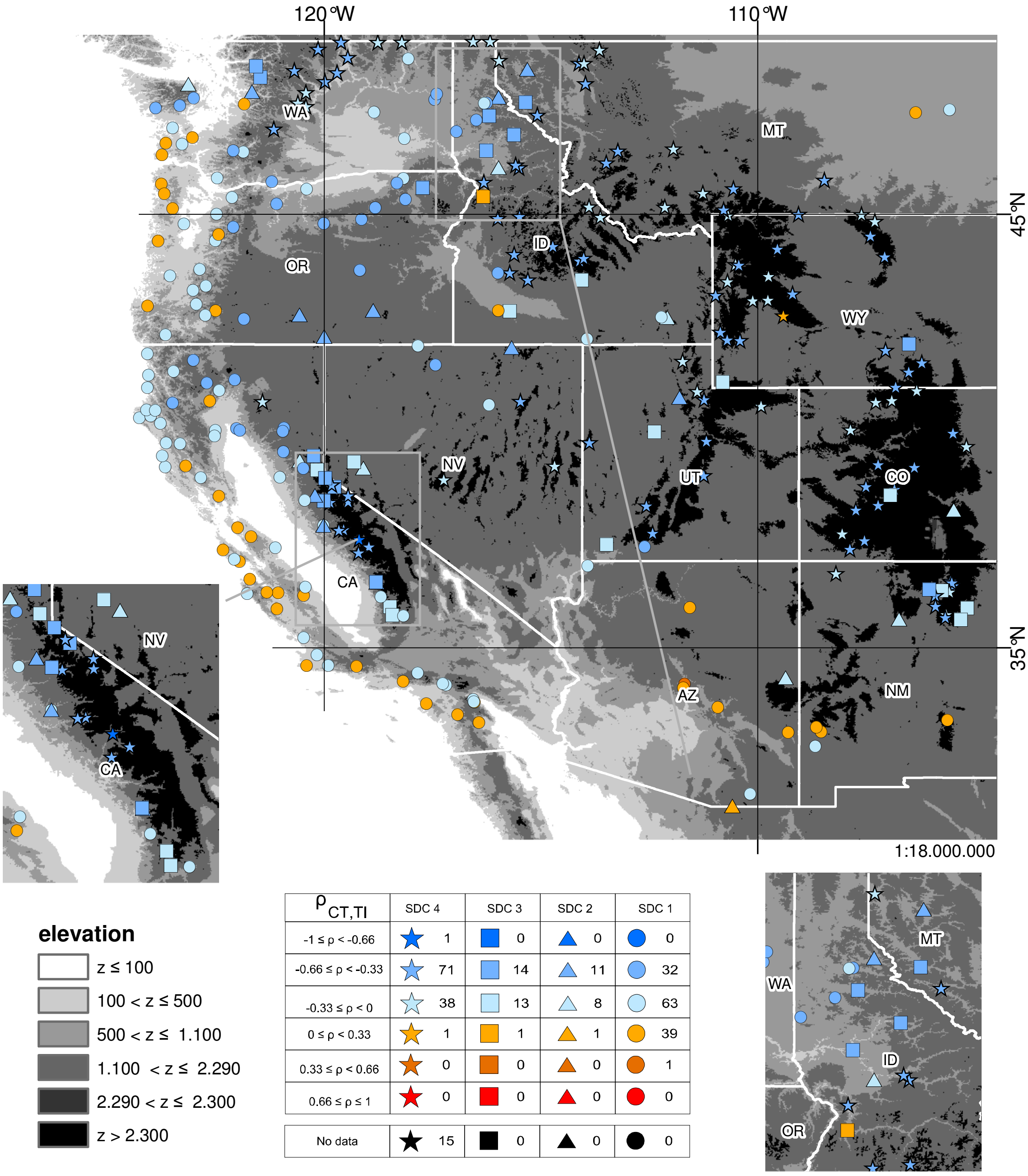
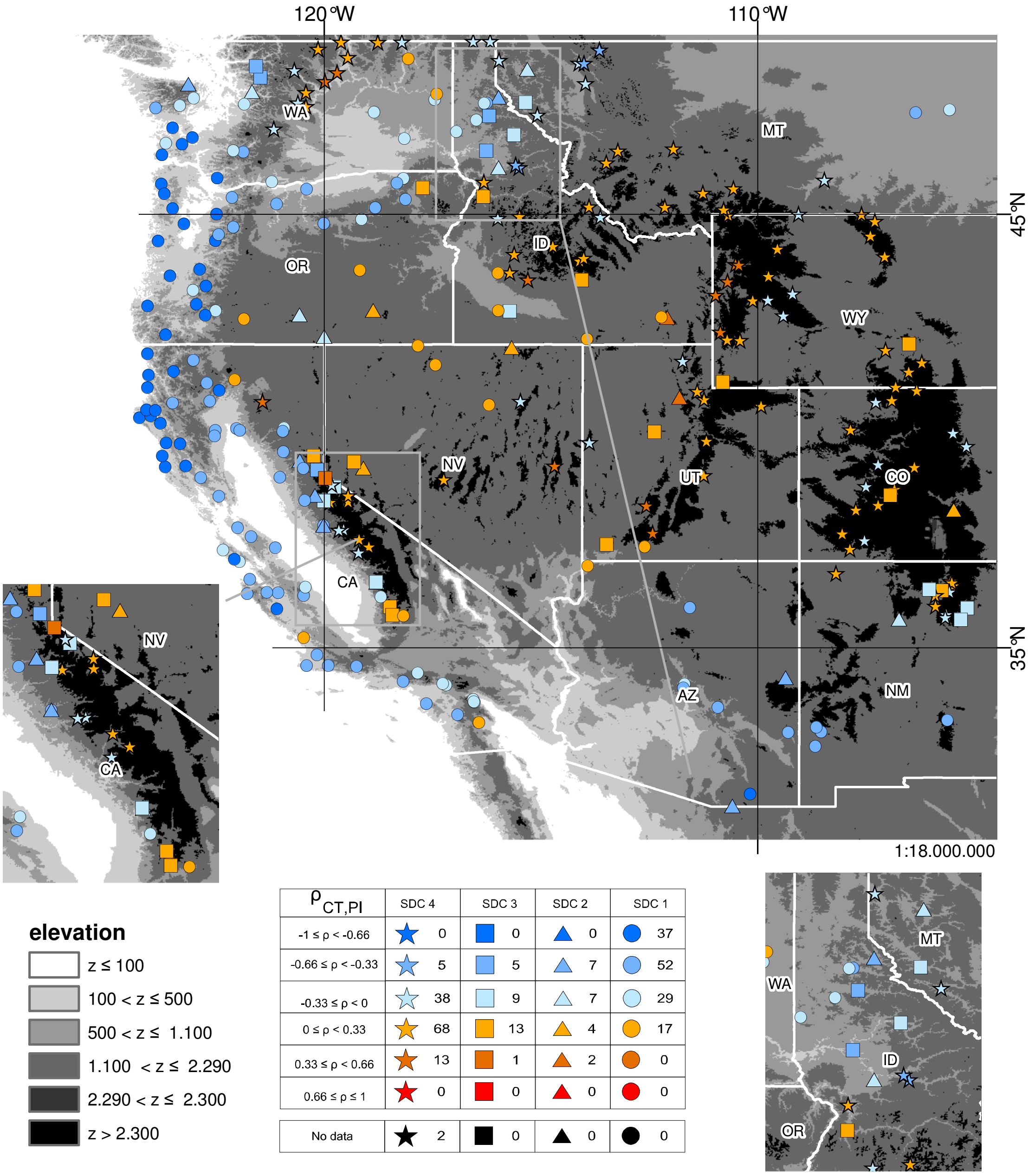


FIGURE 4.3 Correlation of CT and TI

clear majority of streams had a correlation between −0.33 and 0.33 and their CT can be regarded as being mostly unaffected by precipitation directly, as the precipitation is stored as snow and runs off with increasing temperatures in spring.

In Fig. 4.5, the correlation of the snowmelt pulse with TI, the results for SDC 1 were not consistent and the snowmelt pulse for rain dominated streams can be regarded as being unaffected by precipitation. This is only logical, because the snowmelt pulse defines the Snowmelt Domination Categories (see 3.2). SDC 1 is characterized by having a snowmelt pulses ratio of less than 30% and the remaining number of snowmelt pulse are



$\rho_{CT,PI}$	SDC 4	SDC 3	SDC 2	SDC 1
$-1 \le \rho < -0.66$	0	0	0	37
$-0.66 \le \rho < -0.33$	5	5	7	52
$-0.33 \le \rho < 0$	38	9	7	29
$0 \le \rho < 0.33$	68	13	4	17
$0.33 \le \rho < 0.66$	13	1	2	0
$0.66 \le \rho \le 1$	0	0	0	0
No data	2	0	0	0

FIGURE 4.4 Correlation of CT and PI

an insufficient basis for correlating them. This fact is supported by the big number of stream with NaN-values, where a correlation could not be determined.
Compared to correlation of CT with TI ($\rho_{CT,TI}$) SDC 4 were mostly negative, but less so. Most streams had a correlation between 0 and -0.33 and several streams had small positive correlations of less than 0.33. Spatially they were not regionally clustered and the connection to the elevation weakened to $\rho = -0.21$.

The correlation between snowmelt pulse and PI is illustrated in Fig. 4.6. Almost all streams in SDC 1 had a low correlation between -0.33 and 0.33 and the category was

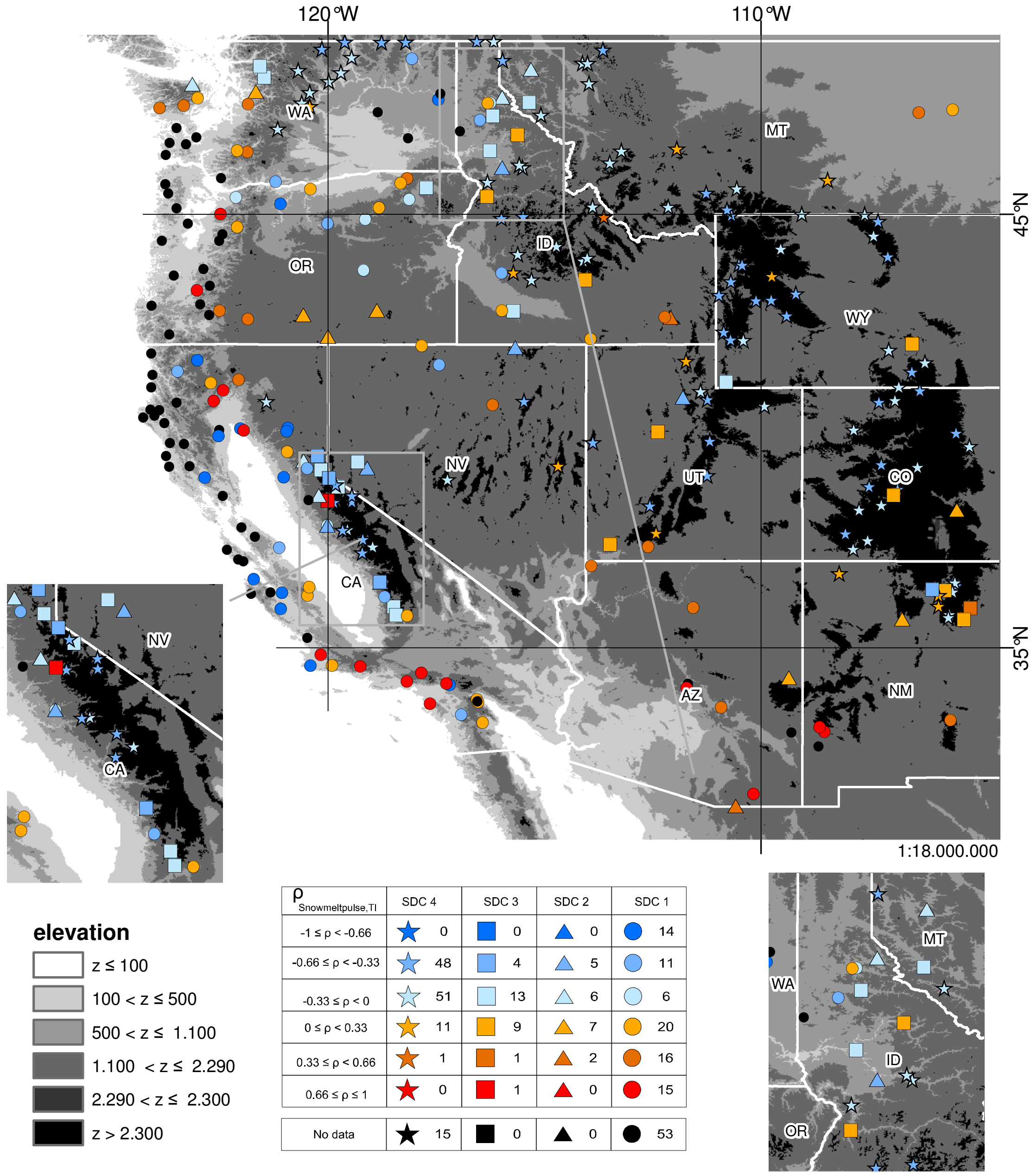


FIGURE 4.5 Correlation of snowmelt pulse and TI

therefore more narrow than in $\rho_{CT,PI}$. SDC 4 was similar to $\rho_{Springpulse,TI}$ spread over all categories and showed the same invariant behavior.

Mantua et al. (1997) mentioned that the PDO as "climate pattern also affects coastal sea and continental surface air temperatures, as well as streamflow in major west coast river systems, from Alaska to California." The map in Fig. 4.7 shows that the influence of PDO on CT was generally weak for the 1948-2008 period. Almost all streams had a correlation less than |0.33| and a general pattern can not be recognized. However the Sierra Nevada streams were all negative correlated as well as the ones in Alaska, which

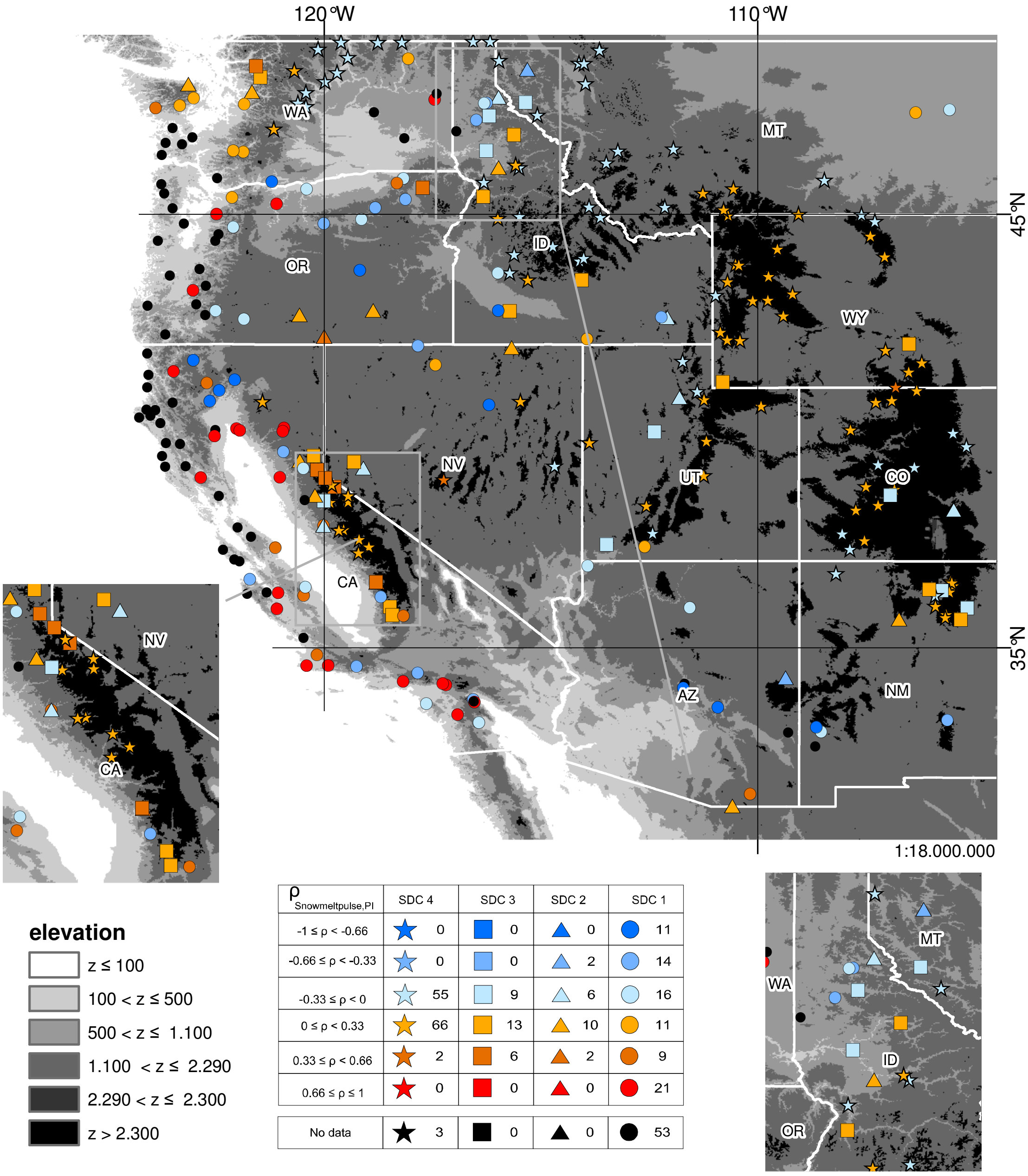


FIGURE 4.6 Correlation of snowmelt pulse and PI

were all in SDC 4 and had the greatest negative correlations. The coastal streams from Washington to North California were all in SDC 1 and had mostly a positive correlation, which would mean a later CT at a higher PDO. But as the PDO is a temperature index and rain dominated streams respond more to precipitation the positive correlation of that streams to PDO is not very meaningful. For the coastal streams in SDC 3 and 4 an influence can be recognized.

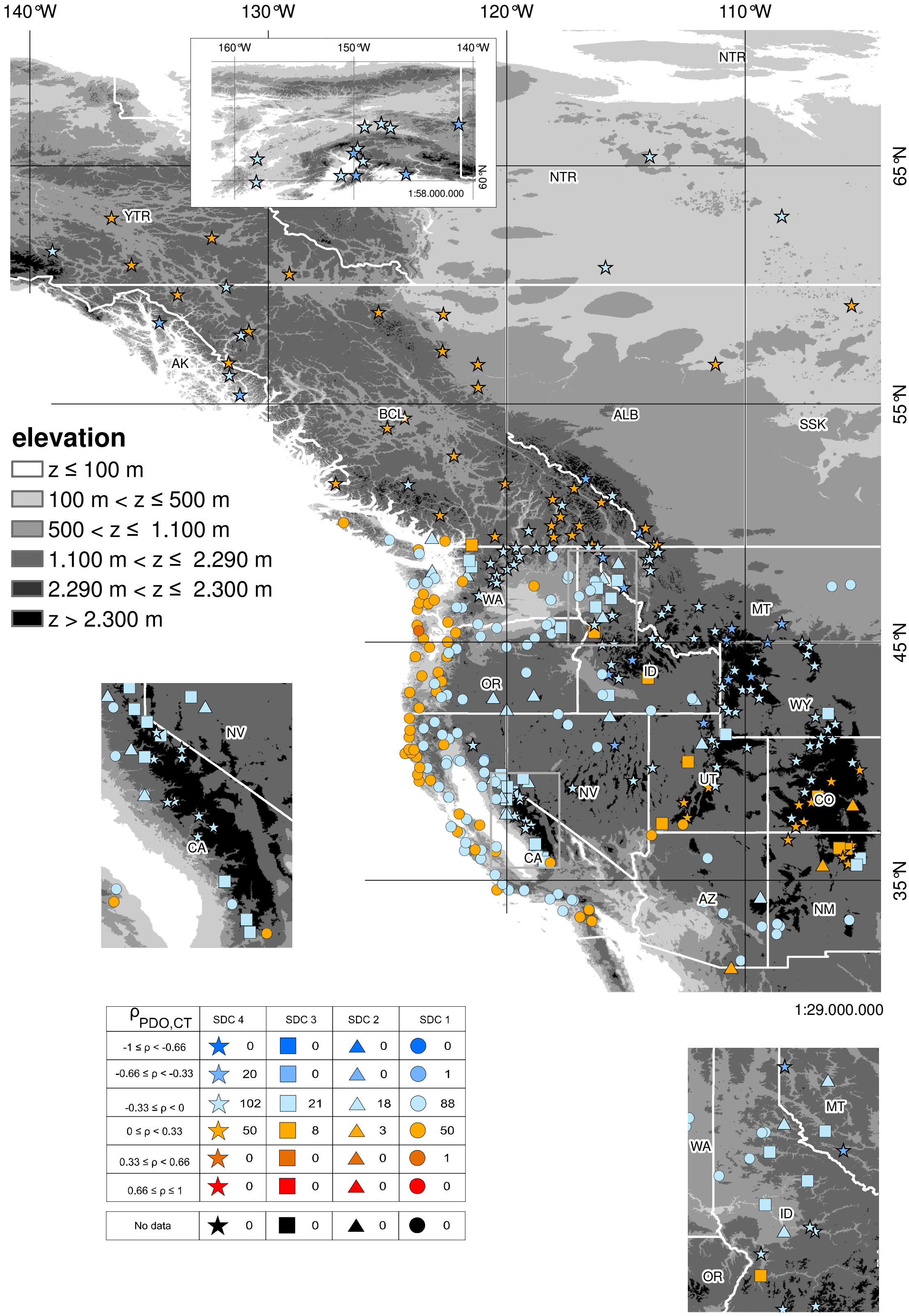


FIGURE 4.7 Correlation of PDO and CT

4.3 Changes in Snowmelt Domination Categories

In the chapter above the Snowmelt Domination Categories were used as method for classifying streams. Hence the ratio of years with and without snowmelt pulses were taken for the whole 1948-2008 observational period. As already mentioned on page 14 the number of snowmelt pulses decreased over the last more than six decades. By splitting this period into two sub periods and comparing the ratios of the first and second period, changes in the ratios may have caused shifts from one category to another. The observational period of 61 was split into three different subsection pairs:

1. first 31 years vs. the later 30 years (Fig. 4.9, page 25)

2. first 41 years vs. the later 20 years (Fig. 4.10, page 26)

3. first 51 years vs. the later 10 years (Fig. 4.11, page 27)

Before the regime changes will be discussed the legend, illustrated in Fig. 4.8, needs some additional explanation. The changes of the 4 categories formed an $i \times j$ matrix with $i, j = 4$. Streams that fall on the main diagonal, where $i = j$, experience no snowmelt regime shifts. The larger the difference $|i - j|$ greater the change in the categories that a stream experienced when comparing two time periods.

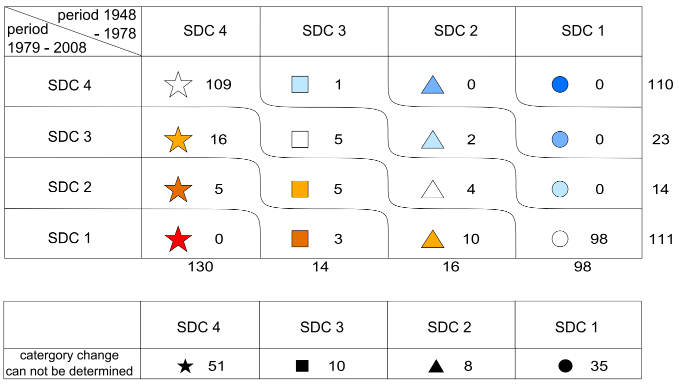


FIGURE 4.8 Example of a legend for snowmelt regime change maps

For example, if a stream changed to a higher category (more snow dominated) it is represented in the upper right triangle of the matrix. If a stream became more rain dominated and changed to a lower category it is represented in the lower left triangle. To illustrate the degree of category change the diverging color scheme were used (Harrower and Brewer, 2003). The main diagonal is comprised of streams that do not shift category from one time period to another and therefore they are mapped in white color. Changes towards more rain domination are mapped on a red color scheme and changes towards more snow domination are mapped in blue. The larger the category shift the darker the hue of the symbol. Each secondary diagonal is represented by the same hue, as all cells on those diagonals experienced the same degree of category change. The symbols are based on the snowmelt domination category of the watershed in the first period. The combination of the symbol and the hue of a given color allows the reader to determine the direction and degree of category shifts. A light orange square for example represents the change from SDC 3 (expressed by that symbol) to SDC 2 (expressed by that color). The legend also provides information about the number of streams experiencing a particular shift. For the light orange square there are 5 streams changing this way. The numbers under and to the right of the matrix are column and row sums and quantify how many streams were in each category in the first and second period. In the first period for example, were 130 streams in SDC 4 but only 110 streams in the second period.

The individual row of entries below the matrix quantifies the number of streams, where a category change could not be determined due to too many missing values. All periods had to have data for at least 66% of the time to avoid the determination of artificial category shifts. To determine the symbol of that streams the overall category for the 1948-2008 period was used.

The first split (compare Fig. 4.9, page 25) cut the observational period into two almost equal halves and fell one to two years after PDO turned into its warm phase. It is particularly noticeable that there is a large number of streams, where a category change could not be determined. As numerous gauges had no measurements before 1960 or even 1965 snowmelt pulse analyses were also not possible. Most streams did not change their categories, particularly the ones in Alaska and Canada. The legend shows 31 streams changed one category towards more rain domination and eight streams changed even two categories. Simultaneously three streams changed one category towards more snow domination. The streams did not change their categories homogeneously. Some streams changed categories isolated and independent from neighbored streams, but 4 clusters of category changes can be recognized:

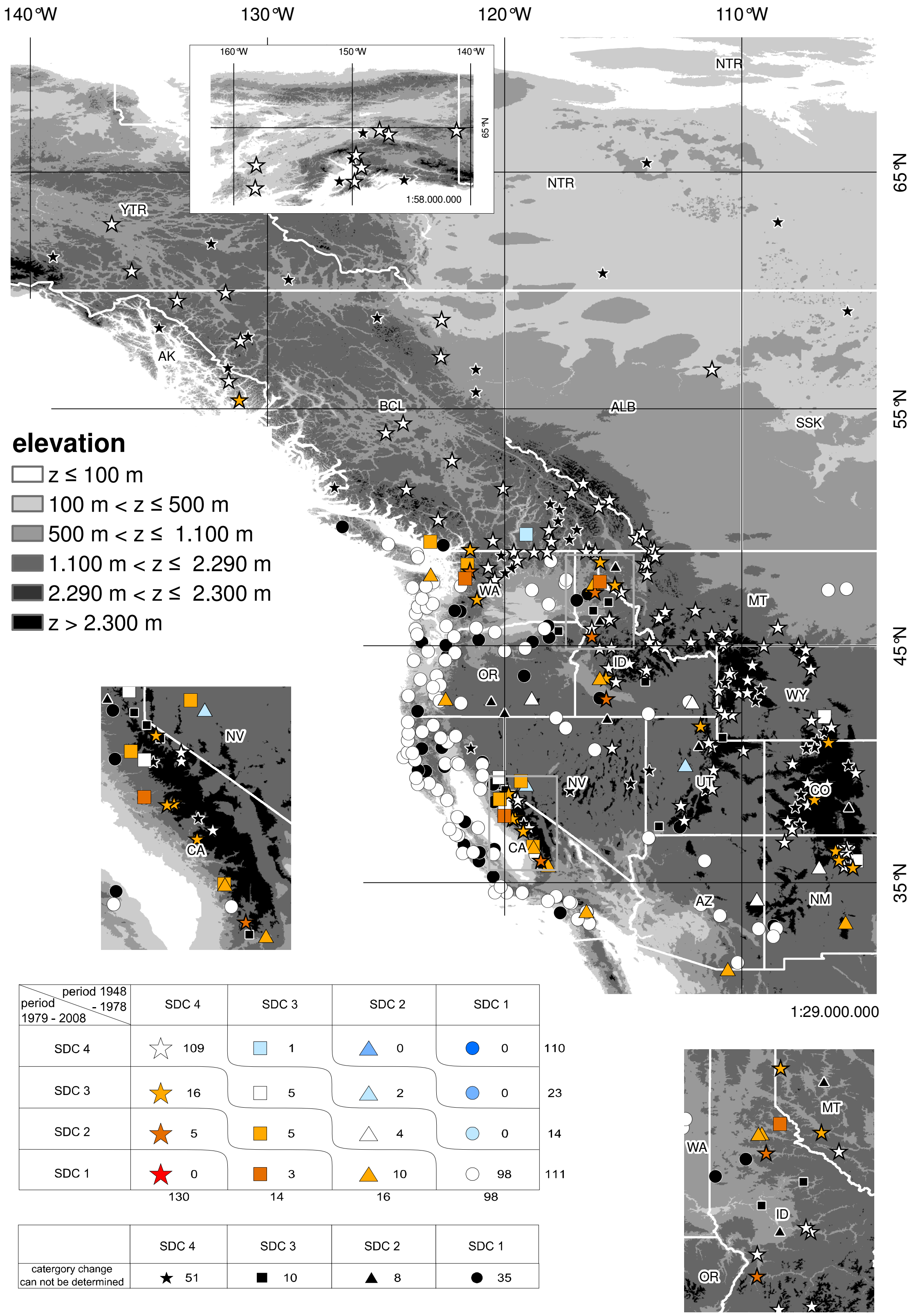
- ▷ North West Washington with 7 category changes
- ▷ North Idaho with 7 category changes (zoom window)
- ▷ Sierra Nevada with 12 category changes (zoom window)
- ▷ North East New Mexico with 3 category changes

The Sierra Nevada were especially affected, because the streams changing categories were in absolute majority. In the zoom window were two streams with opposite changes located very close to each other. One changed from SDC 3 to SDC 4, the other one change vice versa and the question arise why do they change in opposite directions. These streams may be an indication that changes in streamflow timing might be influenced by more than just climate change. Also the topography, orientation, vegetation and soil conditions of the watershed may have influences on streamflow timing.

The second map (Fig. 4.10, page 26) shows the changes for the first 41 years and the last 20 years. This time there were no changes towards more snow domination, but on the other side 48 streams changed towards more rain domination. 34 streams changed one category, 13 changed two and one stream changed even three categories. This stream is also situated in the Sierra Nevada. The legend shows growths and losses of streams of each category. Similar to Fig. 4.9 and also Fig. 4.11 SDC 4 lost streams to the lower categories and SDC 1 won streams from the higher ones. SDC 2 also won streams. Growths from higher categories ran out losses to the lower category. Both intermediate categories can be regarded as transit categories with a positive balance for SDC 2 and a sometimes positive and sometimes negative balance for SCD 3.

The third split was set to compare the first 51 years with the last 10 years (compare Fig. 4.11, page 27) and shows the most recent developments. The legend looks more similar to Fig. 4.9 than to Fig. 4.10, but the spatial distribution differs from both previous comparisons. Nevertheless the four regional clusters still remained. The streams in North East New Mexico already affected by category changes showed more dramatical shifts and further streams also changed towards more rain domination. In North Idaho as well as in North West Washington the changes were less dramatical and there were no changes of more than one category at once. Also less streams changed categories, but there were particularly new streams with category shifts. Several streams, which changed in earlier comparisons, retained the category, but were in a lower one. Therefore their shift happened earlier and did not belong to the latest changes. The Sierra Nevada gained a degradation from the first to the second period, but the situation improved again towards the third comparison. There were no more changes of two categories towards more rain, but in the opposite direction were two shifts over two categories and one over one category.

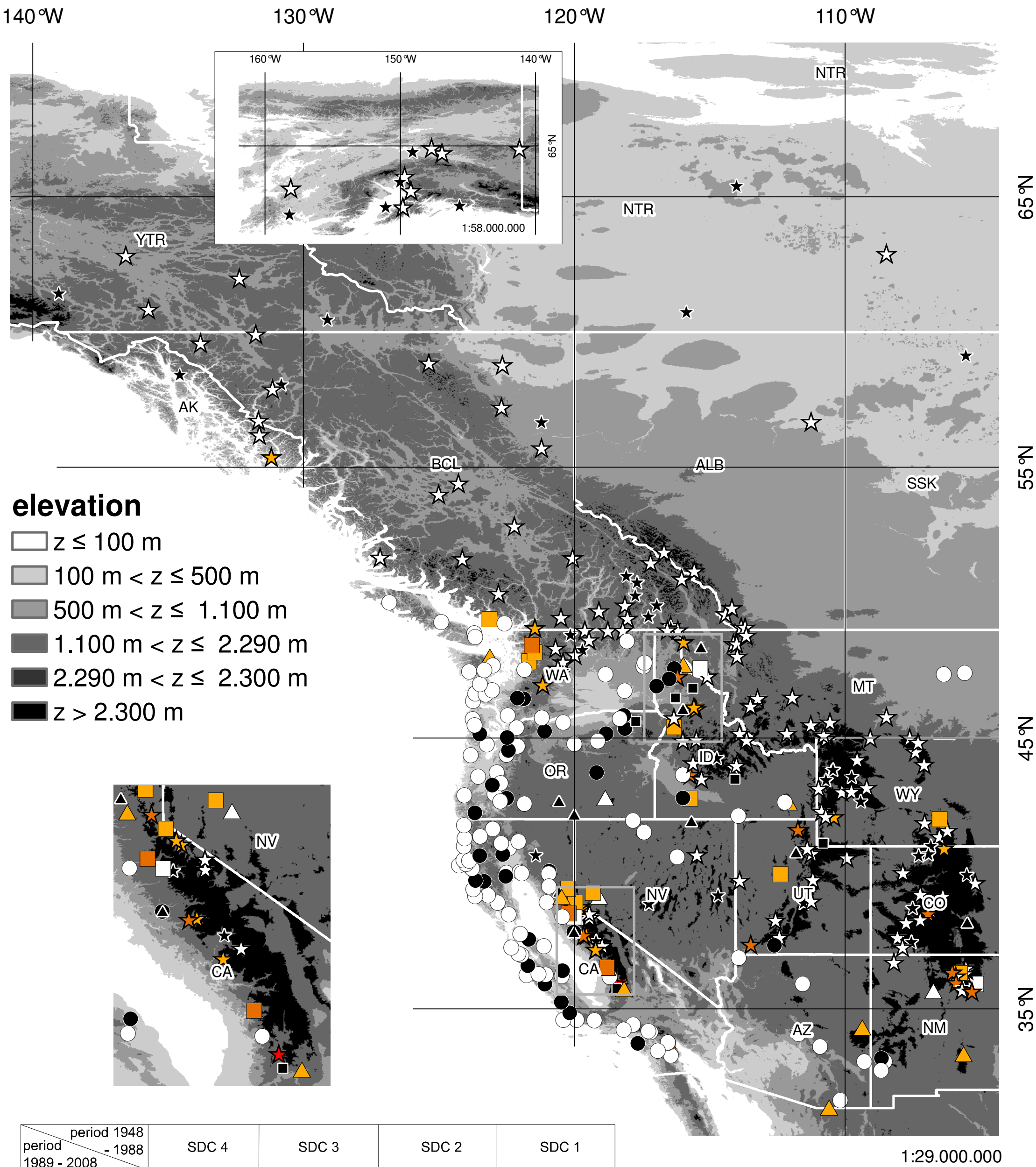
Appendix B (page 43ff.) lists all streams changed categories for each of the three comparisons.



period 1948 - 1978 / period 1979 - 2008	SDC 4	SDC 3	SDC 2	SDC 1	
SDC 4	109	1	0	0	110
SDC 3	16	5	2	0	23
SDC 2	5	5	4	0	14
SDC 1	0	3	10	98	111
	130	14	16	98	

	SDC 4	SDC 3	SDC 2	SDC 1
catergory change can not be determined	51	10	8	35

FIGURE 4.9 Changes in Snowmelt Domination categories between the first 31 years (1948 to 1978) and the later 30 years (1979 - 2008)



period 1948 - 1988 / period 1989 - 2008	SDC 4	SDC 3	SDC 2	SDC 1	
SDC 4	118	0	0	0	118
SDC 3	12	3	0	0	15
SDC 2	10	11	3	0	24
SDC 1	1	3	11	101	116
	141	17	14	101	

	SDC 4	SDC 3	SDC 2	SDC 1
catergory change can not be determined	40	6	9	34

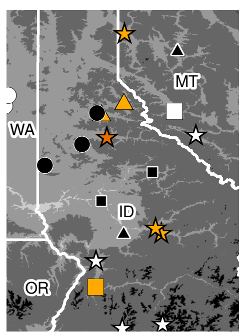
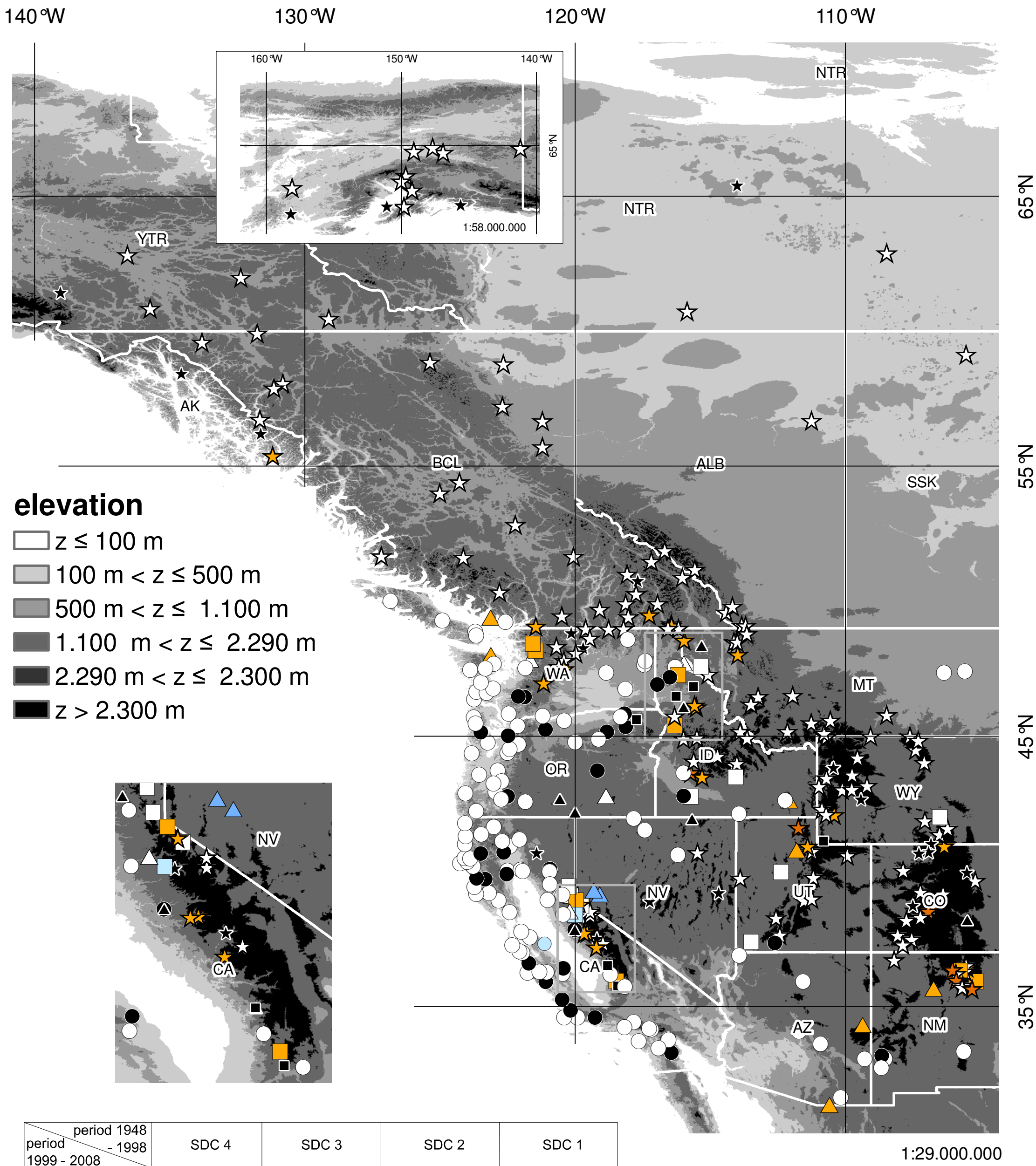


FIGURE 4.10 Changes in Snowmelt Domination categories between the first 41 years (1948 to 1988) and the later 20 years (1989 - 2008)



period 1948 - 1998 / period 1999 - 2008	SDC 4	SDC 3	SDC 2	SDC 1	
SDC 4	☆ 129	□ 1	△ 2	● 0	130
SDC 3	★ 19	□ 9	△ 0	● 0	28
SDC 2	★ 6	■ 8	△ 4	○ 2	20
SDC 1	★ 0	■ 0	▲ 7	○ 108	115
	154	18	11	110	

	SDC 4	SDC 3	SDC 2	SDC 1
catergory change can not be determined	★ 22	■ 6	▲ 9	● 30

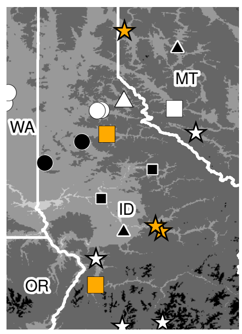


FIGURE 4.11 Changes in Snowmelt domination categories between the first 51 years (1948 to 1998) and the later 10 years (1999 - 2008)

Chapter 5

Visualization

Maps are an useful and powerful tool for presenting spatial data and distributions of phenomena in space and time. But paper based as well as digital maps present their contents only in a static way. The reader is dependent on the given content and has no possibility of interacting with the map to obtain further information. Also big extents of data and different scales pose problems for maps. This study investigated in the possibility of visualizing river discharges for all streams as well as presenting measures and results. The data extents over an area North of $29°$ and Western of $-105°$, but each gauge represents data for the related watershed on a much higher scale. These gaps can be closed by virtual globes technology. A virtual globe (VG) is a digital representation of the earth or any other globe. They are characterized by "a physical independence between the visualization surface (screen) and visualization theme (digital data). This allows cartographers to implement a great number of features that would have been impossible with traditional globes" (Riedel, 2007). Although VGs do not provide any analysis functions this technology "holds many exciting possibilities for environmental science" (Blower et al., 2007). In 2007 existed at least 30 applications (compare Blower et al. (2007)). The most famous ones are probably *Google Earth*, *Microsoft Virtual Earth*, *ArcGIS Explorer* and *Nasa World Wind*. ArcGIS Explorer, Google Earth and Microsoft Virtual Earth are all standalone application which need to be installed. Nasa World Wind is an open-source application and provides a standalone version for Windows, which also need to be installed and a Java based application programming interface (API). This study has used the Nasa World Wind Java SDK (WWJ), which offers several advantages over plug-ins for the other applications:

- ▷ World Wind "provides access to wide range of NASA satellite imagery. [...] Its focus is toward scientific users, so World Wind has a more specialist community than that of Google Earth" (Blower et al., 2007)

- ▷ developed applications can be downloaded and executed as a jar-file. No applications has to be installed. The only requirement is a Java Runtime Environment (JRE)
- ▷ the application can also be directly executed, when it is provided as webstart application (jnlp-file)
- ▷ Java applications are cross-platform and
- ▷ can also be integrated in web-based presentations and applications (Java Applet)

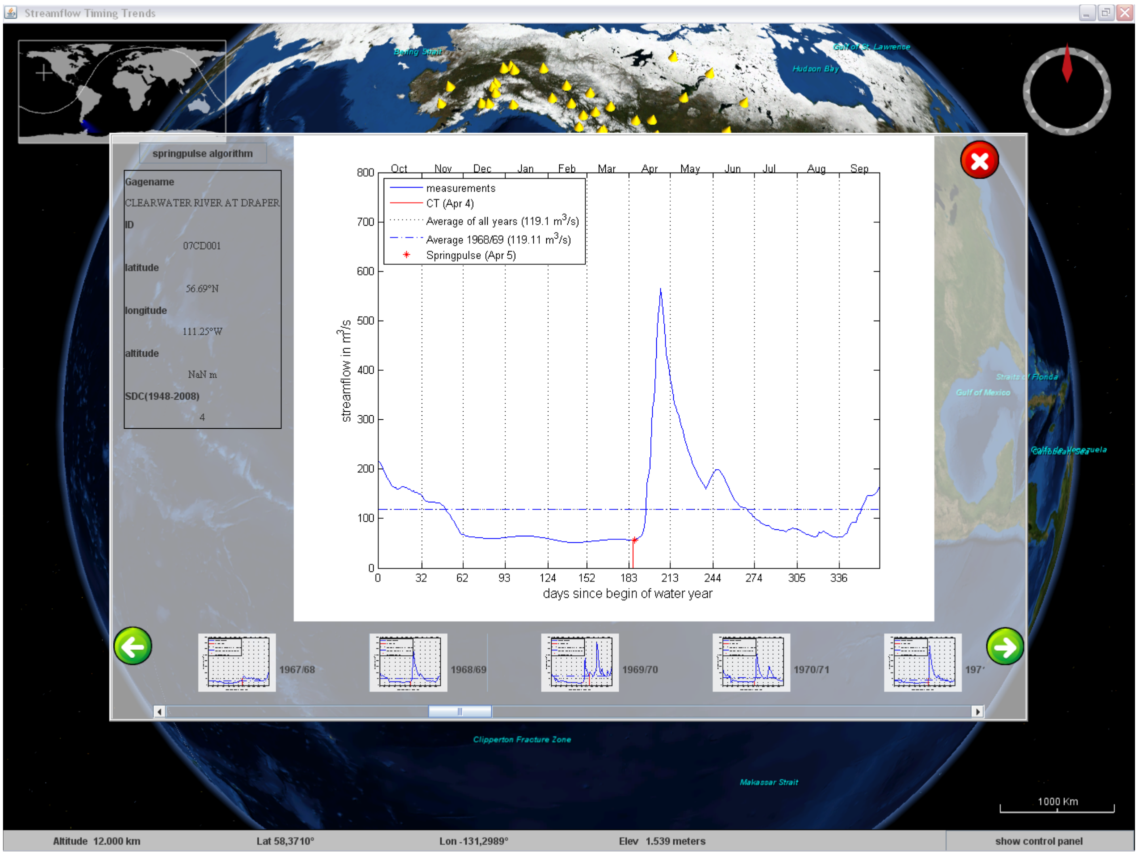


FIGURE 5.1 Screenshot of the application with an open slideshow for a gauge

Fig. 5.1 shows a screenshot of the application. When starting the application only the globe and the gauges marked by yellow cones are visible. By clicking on one of the cones a stream window opens. This provides general information about the gauge, its location and the Snowmelt Domination Category for the observational period (compare 3.2). The user can flip through the hydrographs by using the scrollbar on the bottom and selecting a year. The stream window also features displaying the visualization of the snowmelt pulse algorithm (compare 3.1.2) and the gage's individual trends for CT and snowmelt pulse. Back in the main window a control panel enables the user to search for streams by Name or ID.

The application is available for download at http://webpages.scu.edu/ftp/streamflowtiming and starts after unzipping the zip archive and executing the *start.bat* file. The application streams the data from different webserver. The underlying Blue Marble tiles are downloaded from a NASA Server. The OSM Mapnik Layer, which is included for viewing altitudes between 10 km and 100 km, is streamed from the OpenStreetMap server. All graphics and information presented in the stream window are stored on Santa Clara University webserver and will be streamed on demand. Depending on the speed of the internet connection displaying the stream window may take a moment.

This application uses only a small part of the capabilities that WWJ provides. The source code will be available for download and the application can be adapted and extended to personal requirements and wishes.

Chapter 6

Summary and Discussion

There are strong evidences that the trends towards earlier snowmelt have continued and even increased. Within the last 61 years CT has shifted 6.2 days towards earlier in the year, whereas snowmelt dominated streams experienced stronger shift than rain dominated streams. Accelerated linear trends for the snowmelt pulse could not be determined, but the average number of snowmelt pulses per year has decreased and more streams became dominated by rain.

Classifying streams by the number of denoted snowmelt pulses relative to time periods and comparing this ratios across periods have shown that the number of streams changing towards more rain domination exceeded by far those changing towards more snow domination.

While the changes could be quantified and spatial hotspots were identified, their causes remained blurred. Correlations between streamflow timing measures and climate indicis have shown no strong relationship, which might indicate that changes in streamflow timing have diversified causes.

However, the correlation coefficient is a simple analysis method and reflects the noisiness and direction of a relationship, but gives neither information about the slope of this relationship nor nonlinear dependencies can be well described. Therefore other statistical methods should be examined to describe these relationships more precise. Also further analyses have to be done to quantify the causes separately for each category.

Appendix A

Appendix A

Table A.1 List of used US and Canadian stream gauges, alphabetically ordered

Name	**Lattitude**	**Longitude**	**Altitude**
ALSEA RIVER NEAR TIDEWATE	44.386	-123.831	14.7
AMERICAN RIVER NEAR NILE,	46.978	-121.168	823
ANDREAS C NR PALM SPRINGS	33.76	-116.549	243.8
ANDREWS CR NR MAZAMA WA	48.823	-120.145	1301.5
ANIMAS RIVER AT DURANGO,	37.279	-107.88	1981.7
ANIMAS RIVER AT FARMINGTO	36.721	-108.201	1609.3
ARROYO SECO NR PASADENA C	34.222	-118.177	426.1
ARROYO SECO NR SOLEDAD CA	36.281	-121.322	103.4
ARROYO VALLE BL LANG CN N	37.561	-121.683	228.6
BEAR C NR LAKE THOMAS A E	37.339	-118.973	2245.4
BEAR CREEK AT MORRISON, C	39.653	-105.195	1761.9
BEAVER RIV NR BEAVER UTAH	38.281	-112.574	1889.8
BIG DRY CREEK NEAR VAN NO	47.349	-106.357	710.2
BIG JACKS CR NR BRUNEAU I	42.785	-115.983	847.3
BIG LOST RIVER AT HOWELL	43.998	-114.02	2018.4
BIG ROCK CREEK NEAR VALYE	34.421	-117.839	1234.4
BIG SUR R NR BIG SUR CA	36.246	-121.772	73.2
BLACKSMITH FORK AB U.P.&L	41.622	-111.739	1530.1
BLACKWOOD C NR TAHOE CITY	39.107	-120.161	1900.3
BOISE RIVER NR TWIN SPRIN	43.659	-115.726	992.3
BORREGO PALM C NR BORREGO	33.279	-116.429	353.6
BOULDER CREEK AT MAXVILLE	46.472	-113.233	1447.8
BOUNDARY CREEK NR PORTHIL	48.997	-116.568	539.5

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Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
BRUNEAU RIVER AT ROWLAND	41.933	-115.674	1371.6
BRUNEAU RIVER NR HOT SPRI	42.771	-115.719	792
BUFFALO FORK ABOVE LAVA C	43.837	-110.439	2064.3
BULL C NR WEOTT CA	40.351	-124.003	82.1
BULL LAKE C AB BULL LAKE	43.177	-109.202	1790.4
CACHE CREEK NEAR JACKSON,	43.452	-110.703	2057.4
CAMAS CREEK NEAR UKIAH, O	45.157	-118.819	1093.8
CANTUA CREEK NR CANTUA CR	36.402	-120.433	207.3
CARSON RIVER NEAR FORT CH	39.292	-119.311	1284.6
CHALK CREEK AT COALVILLE	40.921	-111.401	1694.9
CHEHALIS RIVER NEAR DOTY,	46.618	-123.276	92.1
CHEHALIS RIVER NEAR GRAND	46.776	-123.034	37.7
CHENA R AT FAIRBANKS AK	64.846	-147.701	128.9
CHEWAUCAN RIVER NEAR PAIS	42.685	-120.569	1350.3
CISPUS RIVER NEAR RANDLE,	46.442	-121.863	372.3
CITY C NR HIGHLAND CA.+ C	34.144	-117.188	0
CLARK FORK AT ST. REGIS,	47.302	-115.086	792.6
CLARK FORK STANISLAUS R N	38.364	-119.87	1678.6
CLARKS FORK YELLOWSTONE R	45.01	-109.065	1215
CLEAR C A FRENCH GULCH CA	40.695	-122.636	402.5
CLEARWATER RIVER AT OROFI	46.479	-116.256	302
COEUR D'ALENE RIVER NR CA	47.564	-116.307	640.1
COLE C NR SALT SPRINGS DA	38.519	-120.212	1804.4
COLVILLE RIVER AT KETTLE	48.594	-118.061	426.7
COMBINED FLOW OF KERN R A	35.945	-118.477	0
COWLITZ RIVER NR RANDLE,	46.47	-122.098	243.7
COYOTE CREEK NEAR GOLONDR	35.917	-105.164	2068.1
CRAB CREEK AT IRBY, WASH.	47.361	-118.849	422.5
CRYSTAL RIVER AB AVALANCH	39.232	-107.227	2104.6
DEEP CREEK ABOVE ADEL,ORE	42.189	-120.001	1518
DEER C NR VINA CA	40.014	-121.947	146.1
DOLORES RIVER BELOW RICO,	37.639	-108.06	2567.1
DONNER UND BLITZEN RIVER	42.791	-118.867	1296.6
DUCKABUSH RIVER NEAR BRIN	47.684	-123.01	73.6
DUNCAN C NR FRENCH MEADOW	39.136	-120.478	1606.3
DUNGENESS RIVER NEAR SEQU	48.014	-123.131	173.5

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Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
E TWIN C NR ARROWHEAD SPR	34.175	-117.267	466.3
EAST FORK LEWIS RIVER NEA	45.837	-122.465	111.8
EAST FORK RIVER NEAR BIG	42.667	-109.417	2377.4
EAST FORK VIRGIN RIVER NR	37.339	-112.604	1798.3
EAST RIVER AT ALMONT CO.	38.664	-106.848	2440.3
EEL R A SCOTIA CA	40.492	-124.099	10.8
EF CARSON R BL MARKLEEVIL	38.714	-119.764	1645.9
EL TORO C NR SPRECKELS CA	36.583	-121.714	64
ELDER C NR BRANSCOMB CA	39.73	-123.643	424
ELDER C NR PASKENTA CA	40.025	-122.509	218.9
ELK CREEK NEAR TRAIL, ORE	42.675	-122.744	455.3
ELK RIVER AT CLARK, CO.	40.717	-106.915	2215.2
ELKHEAD CREEK NEAR ELKHEA	40.67	-107.284	2086.4
EMBUDO CREEK AT DIXON, NM	36.211	-105.913	1785.7
ENCAMPMENT RIV AB HOG PAR	41.024	-106.824	2520.7
ENTIAT RIVER NEAR ARDENVO	47.819	-120.422	475.8
FISH C NR KETCHIKAN AK	55.392	-131.194	6.1
FISH CREEK ABOVE RESERVOI	39.774	-111.19	2337.8
FISHER RIVER NEAR LIBBY,	48.356	-115.314	650.5
FONTENELLE CR NR HERSCHLE	42.096	-110.416	2118.4
FOREST C NR WILSEYVILLE C	38.403	-120.446	899.2
GALLATIN RIVER NEAR GALLA	45.498	-111.27	1575.1
GALLINAS CREEK NEAR MONTE	35.652	-105.318	2095.5
GARDNER RIVER NEAR MAMMOT	44.993	-110.691	1714.2
GILA RIVER NEAR GILA, NM	33.061	-108.537	1419.1
GILA RIVER NEAR REDROCK,	32.727	-108.675	1246.6
GOOSE CREEK AB TRAPPER CR	42.125	-113.939	1453.9
GRANDE RONDE R AT LA GRAN	45.346	-118.124	861.4
GRAPE CREEK NEAR WESTCLIF	38.186	-105.483	2343.9
GREEN RIVER AT WARREN BRI	43.019	-110.118	2276.3
GREYS RIVER ABOVE RESERVO	43.143	-110.976	1743.5
HALFMOON CREEK NEAR MALTA	39.172	-106.389	2996.2
HAMS FORK BELOW POLE CREE	42.111	-110.709	2272.3
HANGMAN CREEK AT SPOKANE,	47.653	-117.449	523.5
HARDING R NR WRANGELL AK	56.213	-131.637	6.1
HAT CREEK NEAR HAT CREEK	40.687	-121.424	1310.6

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Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
HIGHLAND C BL SPICER MEAD	38.39	-120.006	1932.4
HUMBOLDT R AT PALISADE, N	40.607	-116.201	1470.8
ILLINOIS RIVER NEAR KERBY	42.232	-123.662	365.4
INDIAN C NR CRESCENT MILL	40.078	-120.927	1066.8
JEMEZ RIVER NR JEMEZ,NM	35.662	-106.743	1713.6
JOHN DAY R AT MCDONALD FE	45.588	-120.408	119.6
JOHN DAY RIVER AT SERVICE	44.794	-120.006	497.6
JOHNSON CREEK AT YELLOW P	44.962	-115.499	1419.1
KELSEY C NR KELSEYVILLE C	38.928	-122.842	449.7
KENAI R AT COOPER LANDING	60.493	-149.808	128
KENAI R AT SOLDOTNA AK	60.478	-151.079	10.8
KERN R A KERNVILLE CA	35.754	-118.423	799.1
KETTLE RIVER NEAR LAURIER	48.984	-118.215	434.5
KETTLE RIVER NR FERRY, WA	48.981	-118.765	559.9
KLICKITAT RIVER NEAR PITT	45.757	-121.209	88.1
KUSKOKWIM R AT CROOKED CR	61.871	-158.101	61
L SUSITNA R NR PALMER AK	61.71	-149.23	280
LAKE FORK AT GATEVIEW, CO	38.299	-107.229	2385.9
LAKE FORK PAYETTE RIVER A	44.914	-115.996	1566.7
LAMOILLE C NR LAMOILLE, N	40.691	-115.476	1902
LEMHI RIVER NR LEMHI ID	44.94	-113.638	1511.8
LITTLE BIGHORN RIVER AT S	45.007	-107.614	1325.9
LITTLE COLORADO R ABV LYM	34.314	-109.362	1831.8
LITTLE COLORADO RIVER NEA	35.926	-111.567	1212.9
LITTLE R NR TRINIDAD CA	41.011	-124.081	5.4
LITTLE RIVER AT PEEL, ORE	43.253	-123.025	252.5
LITTLE SALMON RIVER AT RI	45.413	-116.325	536.4
LITTLE SPOKANE RIVER AT D	47.785	-117.403	484.6
LITTLE WOOD RIVER AB HIGH	43.492	-114.058	1621.5
LOCHSA RIVER NR LOWELL, I	46.151	-115.586	1600.2
LOPEZ C NR ARROYO GRANDE	35.236	-120.471	176.8
LOS GATOS C AB NUNEZ CYN	36.215	-120.47	324.7
LUCKIAMUTE RIVER NEAR SUV	44.783	-123.233	52.4
M FK JOHN DAY R AT RITTER	44.889	-119.14	775.6
M TUOLUMNE R A OAKLAND RE	37.828	-120.011	853.4
MARBLE F KAWEAH R (TOTAL	36.519	-118.801	0

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Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
MARSH CREEK NR MCCAMMON I	42.63	-112.225	1268
MARTIN C NR PARADISE VALL	41.533	-117.428	1432.6
MATTOLE R NR PETROLIA CA	40.312	-124.263	12.2
MC DERMITT C NR MC DERMIT	41.967	-117.834	1385.3
MCCLOUD R NR MCCLOUD CA	41.188	-122.064	826.4
MEDICINE BOW R AB SEMINOE	42.01	-106.512	1955.4
MENDENHALL R NR AUKE BAY	58.43	-134.573	18.3
MERCED R A HAPPY ISLES BR	37.732	-119.558	1224.3
MERCED R A POHONO BRIDGE	37.717	-119.665	1177
METHOW RIVER NR PATEROS,	48.077	-119.984	274.3
MF EEL R NR DOS RIOS CA	39.706	-123.324	274.8
MF KAWEAH R NR POTWISHA C	36.513	-118.791	0
MIDDLE BOULDER CREEK AT N	39.962	-105.504	2495.1
MIDDLE FORK FLATHEAD RIVE	48.495	-114.009	953.6
MIDDLE FORK ROCK CREEK NE	46.195	-113.5	1641.6
MILL C NR LOS MOLINOS CA	40.055	-122.023	117.3
MINAM RIVER AT MINAM,OREG	45.62	-117.726	774.3
MOGOLLON CREEK NEAR CLIFF	33.167	-108.649	1658.1
MOLALLA R AB PC NR WILHOI	45.01	-122.479	241.2
MORES CREEK AB ROBIE CREE	43.648	-115.989	951
MOYIE RIVER AT EASTPORT,	48.999	-116.179	798.6
MUDDY CREEK NEAR EMERY, U	38.982	-111.249	1950.7
N F FLATHEAD RIVER NEAR C	48.496	-114.127	958.8
N FK BIG LOST RIVER AT WI	43.933	-114.113	2078.7
N FK COEUR D ALENE RIV AB	47.708	-115.976	757.4
N FK COEUR D ALENE RIVER	47.572	-116.253	640.1
N PLATTE RIV AB SEMINOE R	41.872	-107.057	1950.9
N YUBA R BL GOODYEARS BAR	39.525	-120.937	747.7
N.F. CLEARWATER RIVER NR	46.841	-115.62	506
NAPA RIVER NEAR ST. HELEN	38.498	-122.427	51.9
NASELLE RIVER NEAR NASELL	46.374	-123.742	7.3
NAVARRO R NR NAVARRO CA	39.172	-123.668	1.5
NEHALEM RIVER NEAR FOSS,	45.704	-123.754	9.9
NF AMERICAN R A NORTH FOR	38.936	-121.023	217.9
NF OF MF TULE R NR SPRING	36.175	-118.695	0
NF SKOKOMISH R BLW STRCSE	47.514	-123.329	232.3

Continued on next page

Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
NO SANTIAM R BL BOULDER C	44.707	-122.1	484.7
NORTH BRUSH CREEK NEAR SA	41.37	-106.52	2444.5
NORTH FORK POWDER RIVER N	44.028	-107.08	2493.3
NORTH PLATTE RIVER NEAR N	40.938	-106.338	2380.6
NOYO R NR FORT BRAGG CA	39.428	-123.737	3.6
NUYAKUK R NR DILLINGHAM A	59.936	-158.188	99.1
OKANOGAN RIVER AT MALOTT,	48.281	-119.703	238.8
OKANOGAN RIVER NEAR TONAS	48.632	-119.461	262.4
ORESTIMBA C NR NEWMAN CA	37.316	-121.124	65.8
PACIFIC CREEK AT MORAN, W	43.851	-110.516	2048.3
PALM CYN C NR PALM SPRING	33.745	-116.535	213.4
PALOUSE RIVER AT HOOPER,	46.759	-118.148	317.2
PALOUSE RIVER NR POTLATCH	46.915	-116.95	748.3
PECOS R NR PECOS, NM	35.708	-105.682	2286.9
PESCADERO C NR PESCADERO	37.261	-122.328	19
PINE CREEK ABOVE FREMONT	43.031	-109.769	2270.8
PITMAN C BL TAMARACK C CA	37.199	-119.213	2139.7
PORTNEUF RIVER AT TOPAZ I	42.625	-112.089	1499
POWER C NR CORDOVA AK	60.587	-145.618	10.2
PRICKLY PEAR CREEK NEAR C	46.519	-111.946	1239.7
PROSPECT CREEK AT THOMPSO	47.586	-115.354	726.2
QUARTZVILLE CREEK NEAR CA	44.54	-122.435	320
QUINAULT RIVER AT QUINAUL	47.458	-123.888	56.3
RED BUTTE CREEK AT FT. DO	40.78	-111.805	1645.9
REDWATER RIVER AT CIRCLE	47.414	-105.575	729.8
REDWOOD C A ORICK CA	41.299	-124.05	1.6
RIO GRANDE BELOW TAOS JUN	36.32	-105.754	1844.1
RIO GRANDE DEL RANCHO NEA	36.298	-105.582	2206.1
RIO HONDO NEAR VALDEZ, N.	36.542	-105.556	2331.7
RIO LUCERO NEAR ARROYO SE	36.508	-105.53	2454.1
RIO MORA NEAR TERRERO, NM	35.777	-105.658	2404.9
RIO OJO CALIENTE AT LA MA	36.35	-106.044	1938.2
RIO PUEBLO DE TAOS NEAR T	36.439	-105.503	2249.4
RIO RUIDOSO AT HOLLYWOOD,	33.327	-105.627	1956.8
ROCK CR AB KING CANYON CA	41.585	-106.222	2374.4
ROGUE RIVER ABOVE PROSPEC	42.775	-122.499	798.6

Continued on next page

Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
ROW RIVER ABOVE PITCHER C	43.736	-122.872	261
RUBY RIVER ABOVE RESERVOI	45.175	-112.148	1658.2
RUSSIAN R NR UKIAH CA	39.196	-123.194	182.6
S F TRINITY RIVER BL HYAM	40.65	-123.493	369.2
S YUBA R NR CISCO CA	39.321	-120.563	1682.5
S. UMPQUA RIVER @ TILLER,	42.931	-122.947	302.3
S.F. CLEARWATER RIVER AT	46.087	-115.976	399.9
S.F. WALLA WALLA RIVER NE	45.83	-118.169	624.8
SACRAMENTO R A DELTA CA	40.94	-122.416	327.7
SAGEHEN C NR TRUCKEE CA	39.432	-120.237	1926.3
SALINA CREEK NEAR EMERY U	38.912	-111.53	2133.6
SALMON R A SOMES BAR CA	41.378	-123.476	147.2
SALMON RIVER AT SALMON ID	45.183	-113.894	1192.1
SALMON RIVER AT WHITE BIR	45.75	-116.323	430.6
SALMON RIVER BL YANKEE FO	44.268	-114.732	1798.3
SALSIPUEDES C NR LOMPOC C	34.589	-120.408	67.1
SALT RIVER NEAR ROOSEVELT	33.619	-110.921	663.6
SAN ANTONIO R NR LOCKWOOD	35.897	-121.087	242.3
SAN FRANCISCO RIVER AT CL	33.049	-109.295	1047.3
SAN JOAQUIN R A MILLER CR	37.511	-119.196	1392.9
SAN LORENZO C BL BITTERWA	36.268	-121.065	131.6
SAN LORENZO R A BIG TREES	37.044	-122.071	69.2
SAN PEDRO RIVER AT CHARLE	31.626	-110.174	1205.2
SAN RAMON C A SAN RAMON C	37.773	-121.994	161.5
SANDY RIVER NEAR MARMOT,	45.392	-122.128	222.5
SANTA CLARA RIVER NR PINE	37.383	-113.482	2023.9
SANTA CRUZ CR NR SANTA YN	34.597	-119.908	238.8
SANTA CRUZ RIVER NEAR CUN	35.965	-105.904	1969
SANTA CRUZ RIVER NEAR LOC	31.355	-110.589	1408.2
SANTIAGO C A MODJESKA CA	33.713	-117.644	368.8
SATSOP RIVER NEAR SATSOP,	47.001	-123.494	0
SAUK R ABV WHITECHUCK R N	48.169	-121.469	283.5
SAUK RIVER NEAR SAUK, WAS	48.425	-121.567	81.1
SCOTT RIVER NEAR FORT JON	41.641	-123.014	799.7
SELWAY RIVER NR LOWELL, I	46.087	-115.513	1719.1
SESPE CREEK NR WHEELER SP	34.578	-119.257	1067

Continued on next page

Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
SEVIER RIVER AT HATCH UTA	37.651	-112.429	2094
SF BOISE RIVER NR FEATHER	43.494	-115.306	1285.8
SF EEL RIVER NR MIRANDA C	40.182	-123.775	66.3
SF KERN R NR ONYX CA	35.737	-118.173	883.9
SF PAYETTE RIVER AT LOWMA	44.085	-115.621	1155.2
SF TUOLUMNE RIVER NR OAKL	37.822	-120.012	853.4
SHELL CREEK ABOVE SHELL C	44.508	-107.403	2758.4
SILVIES RIVER NEAR BURNS,	43.715	-119.176	1278.6
SIMILKAMEEN RIVER NEAR NI	48.985	-119.617	346.8
SISQUOC RIVER NEAR SISQUO	34.84	-120.167	190.3
SKYKOMISH RIVER NEAR GOLD	47.838	-121.666	63.8
SMITH FORK NEAR CRAWFORD,	38.728	-107.506	2161.3
SMITH R NR CRESCENT CITY	41.792	-124.075	24.2
SMITHS FORK NEAR BORDER,	42.293	-110.868	2048.3
SNOQUALMIE RIVER NEAR SNO	47.545	-121.841	36.6
SOQUEL CR AT SOQUEL CALIF	36.991	-121.955	6.5
SOUTH FORK COQUILLE RIVER	42.892	-124.069	60.2
SOUTH FORK SHOSHONE RIVER	44.208	-109.554	1889.8
SOUTH SANTIAM RIVER BELOW	44.393	-122.51	231.6
SOUTH TWIN R NR ROUND MOU	38.888	-117.244	1914.1
SPANISH CREEK ABOVE BLACK	40.003	-120.953	954
SPRAGUE RIVER NEAR CHILOQ	42.585	-121.849	1280.9
ST. JOE RIVER AT CALDER,	47.275	-116.188	662
ST. MARIES RIVER NEAR SAN	47.176	-116.492	784.7
STEAMBOAT CREEK NEAR GLID	43.35	-122.728	344
STEHEKIN RIVER AT STEHEKI	48.33	-120.691	334.8
STEPTOE CR NR ELY NV	39.201	-114.688	2250
SULPHUR CREEK ABV RESERVO	41.129	-110.806	2206.8
SUSITNA R AT GOLD CREEK A	62.768	-149.691	206.2
SWAN RIVER NEAR BIGFORK,	48.024	-113.979	933.5
SWIFTCURRENT CREEK AT MAN	48.799	-113.656	1486.4
TAHQUITZ C NR PALM SPRING	33.805	-116.558	232.4
TALKEETNA R NR TALKEETNA	62.354	-150.012	121.9
TANANA R AT NENANA AK	64.565	-149.092	103.2
TEMECULA CREEK NEAR AGUAN	33.459	-116.923	484.6
THOMES C A PASKENTA CA	39.888	-122.528	219.5

Continued on next page

Table A.1 – continued from previous page

Name	Lattitude	Longitude	Altitude
TOMICHI CREEK AT GUNNISON	38.522	-106.94	2325.2
TONGUE RIVER NEAR DAYTON,	44.849	-107.304	1237.5
TRINITY R AB COFFEE C NR	41.111	-122.704	773.3
TROUT CR NR CALLAO UTAH	39.744	-113.889	1889.8
TROUT CREEK NR TAHOE VALL	38.92	-119.971	1902.4
UMATILLA RIVER AB MEACHAM	45.72	-118.322	565.3
UMPQUA RIVER NEAR ELKTON,	43.586	-123.554	27.6
UNCOMPAHGRE RIVER NEAR RI	38.184	-107.745	2096.3
VALLECITO CREEK NEAR BAYF	37.478	-107.543	2409.8
VAN DUZEN RIVER NR BRIDGE	40.481	-123.89	109.2
VERDE RIVER BLW TANGLE CR	34.073	-111.716	618.4
VERNON CREEK NEAR VERNON,	39.979	-112.379	1889.8
VIRGIN RIVER AT LITTLEFIE	36.892	-113.924	537.6
W WALKER R BL L WALKER R	38.38	-119.449	2009.1
W WALKER R NR COLEVILLE,	38.515	-119.454	1682.5
WALKER R NR WABUSKA, NV	39.153	-119.097	1304.5
WEBER RIVER NEAR OAKLEY,	40.736	-111.246	2011.7
WENATCHEE RIVER AT MONITO	47.499	-120.423	207.3
WENATCHEE RIVER AT PESHAS	47.583	-120.613	313.3
WEST FORK CARSON RIVER AT	38.769	-119.832	1754
WET BOTTOM CREEK NR CHILD	34.161	-111.692	707.1
WHITE RIVER BELOW TYGH VA	45.242	-121.094	265.2
WHITE RIVER NEAR MEEKER,	40.034	-107.862	1920.2
WHITEROCKS RIVER NEAR WHI	40.587	-109.927	2182.4
WILLAMINA CREEK NEAR WILL	45.143	-123.493	96
WILLAPA RIVER NR WILLAPA,	46.651	-123.651	1.1
WILSON RIVER NEAR TILLAMO	45.485	-123.689	21.9
WIND RIVER NEAR DUBOIS, W	43.579	-109.759	2191.1
YAAK RIVER NEAR TROY, MT	48.562	-115.969	560.5
YELLOWSTONE RIVER AT BILL	45.797	-108.47	939.2
YELLOWSTONE RIVER AT CORW	45.112	-110.794	1548.1
YELLOWSTONE RIVER NEAR LI	45.597	-110.565	1384.6
YUKON R AT EAGLE AK	64.789	-141.198	259.1

Table A.2 List of used Canadian stream gauges, alphabetically ordered.
Altitude values were not available for Canadian Gauges and are thus not included in the table

Name	**Lattitude**	**Longitude**
ANDERSON CREEK NEAR NELSON	49.5	-117.26
ARROW CREEK NEAR ERICKSON	49.16	-116.45
ATLIN RIVER NEAR ATLIN	59.6	-133.81
BARNES CREEK NEAR NEEDLES	49.91	-118.13
BELLY RIVER NEAR MOUNTAIN VIEW	49.1	-113.7
BLUEBERRY RIVER BELOW AITKEN CREEK	56.68	-121.22
BOW RIVER AT BANFF	51.18	-115.57
CAPILANO RIVER ABOVE INTAKE	49.4	-123.14
CHEMAINUS RIVER NEAR WESTHOLME	48.88	-123.7
CHILKO RIVER AT OUTLET OF CHILKO LAKE	51.63	-124.14
CHILLIWACK R. AT OUTLET OF CHILLIWACK L.	49.08	-121.46
CLEARWATER RIVER AT DRAPER	56.69	-111.25
CLEARWATER RIVER NEAR CLEARWATER STN.	51.66	-120.07
COLUMBIA RIVER AT DONALD	51.48	-117.18
COPPERMINE RIVER AT OUTLET POINT LAKE	65.41	-114.01
CROWSNEST RIVER AT FRANK	49.6	-114.41
DEER CREEK AT DEER PARK	49.43	-118.04
FOND DU LAC RIVER AT OUTLET OF BLACK LAKE	59.15	-105.54
FRANCES RIVER NEAR WATSON LAKE	60.47	-129.12
HAY R NEAR HAY RIVER	60.75	-115.86
ILLECILLEWAET RIVER AT GREELEY	51.01	-118.08
INCOMAPPLEUX RIVER NEAR BEATON	50.77	-117.68
ISKUT RIVER BELOW JOHNSON RIVER	56.74	-131.67
KASLO RIVER BELOW KEMP CREEK	49.91	-116.95
KLUANE RIVER AT OUTLET OF KLUANE LAKE	61.43	-139.05
KOKSILAH RIVER AT COWICHAN STATION	48.73	-123.67
KOOTENAY RIVER AT KOOTENAY CROSSING	50.89	-116.04
KUSKANAX CREEK NEAR NAKUSP	50.28	-117.75
LILLOOET RIVER NEAR PEMBERTON	50.34	-122.8
LOCKHART R AT OUTLET ARTILLERY L	62.9	-108.47
MISTAYA RIVER NEAR SASKATCHEWAN CROSSING	51.88	-116.69
MUSKWA RIVER NEAR FORT NELSON	58.79	-122.66
NORTH ALOUETTE R.- 232ND ST.- MAPLE RIDGE	49.24	-122.58
OLDMAN RIVER NEAR WALDRON'S CORNER	49.81	-114.18

Continued on next page

Table A.2 – continued from previous page

Name	**Lattitude**	**Longitude**
PELLY RIVER AT PELLY CROSSING	62.83	-136.58
PINE RIVER AT EAST PINE	55.72	-121.21
QUESNEL RIVER NEAR QUESNEL	52.84	-122.22
ROSS RIVER AT ROSS RIVER	61.99	-132.38
SIKANNI CHIEF RIVER NEAR FORT NELSON	57.23	-122.69
SIMILKAMEEN RIVER AT PRINCETON	49.46	-120.5
SPROAT RIVER NEAR ALBERNI	49.29	-124.91
STELLAKO RIVER AT GLENANNAN	54.01	-125.01
STIKINE RIVER AT TELEGRAPH CREEK	57.9	-131.15
STUART RIVER NEAR FORT ST. JAMES	54.42	-124.28
SULLIVAN CREEK NEAR CANYON	49.1	-116.43
SWIFT RIVER NEAR SWIFT RIVER	59.93	-131.77
TAKHINI RIVER NEAR WHITEHORSE	60.85	-135.74
TOAD RIVER ABOVE NONDA CREEK	58.86	-125.38
TUYA RIVER NEAR TELEGRAPH CREEK	58.07	-130.82
WANNOCK RIVER AT OUTLET OF OWIKENO L.	51.68	-127.18
WATERTON RIVER NEAR WATERTON PARK	49.11	-113.84
WEST KETTLE RIVER NEAR MCCULLOCH	49.7	-119.09
ZEBALLOS RIVER NEAR ZEBALLOS	50.01	-126.84

Appendix B

Appendix B

Table B.1 Streams changed Snowmelt Domination Categories from 1948 - 1978 period to 1979 - 2009 period), alphabetically ordered

ID	Name
Changes from SDC 4 to SDC 32	
12488500	AMERICAN RIVER NEAR NILE
10113500	BLACKSMITH FORK AB UP and L CO.S DAM NR HYRUM
13185000	BOISE RIVER NR TWIN SPRINGS ID
08MH016	CHILLIWACK R. AT OUTLET OF CHILLIWACK L.
15072000	FISH C NR KETCHIKAN AK
8380500	GALLINAS CREEK NEAR MONTEZUMA
11264500	MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA
11266500	MERCED R A POHONO BRIDGE NR YOSEMITE CA
6620000	NORTH PLATTE RIVER NEAR NORTHGATE
11237500	PITMAN C BL TAMARACK C CA
12390700	PROSPECT CREEK AT THOMPSON FALLS MT
8289000	RIO OJO CALIENTE AT LA MADERA
8291000	SANTA CRUZ RIVER NEAR CUNDIYO
9119000	TOMICHI CREEK AT GUNNISON
10310000	WEST FORK CARSON RIVER AT WOODFORDS
12304500	YAAK RIVER NEAR TROY MT
Changes from SDC 3 to SDC 2	
08GA010	CAPILANO RIVER ABOVE INTAKE

Continued on next page

Table B.1 – continued from previous page

ID	Name
10312000	CARSON RV NR FORT CHURCHILL
11315000	COLE C NR SALT SPRINGS DAM CA
11208001	MARBLE F KAWEAH R (TOTAL FLOW) A POTWISHA CAMP CA
12189500	SAUK RIVER NEAR SAUK
Changes from SDC 2 to SDC 1	
12413500	COEUR D ALENE RIVER NR CATALDO ID
12048000	DUNGENESS RIVER NEAR SEQUIM
11206501	MF KAWEAH R NR POTWISHA CAMP(TOTAL FLOW) CA
13200000	MORES CREEK AB ROBIE CREEK NR ARROWROCK DAM ID
12413000	NF COEUR D ALENE RIVER AT ENAVILLE ID
8387000	RIO RUIDOSO AT HOLLYWOOD
14328000	ROGUE RIVER ABOVE PROSPECT
9480000	SANTA CRUZ RIVER NEAR LOCHIEL
11189500	SF KERN R NR ONYX CA
10258000	TAHQUITZ C NR PALM SPRINGS CA
Changes from SDC 3 to SDC 2	
13168500	BRUNEAU RIVER NR HOT SPRING ID
11186001	COMBINED FLOW OF KERN R AND KERN R NO 3 CA
13316500	LITTLE SALMON RIVER AT RIGGINS ID
12186000	SAUK RIVER AB WHITECHUCK RIVER NEAR DARRINGTON
12414500	ST JOE RIVER AT CALDER ID 13
Changes from SDC 3 to SDC 1	
11282000	M TUOLUMNE R A OAKLAND RECREATION CAMP CA
12411000	NF COEUR D ALENE R AB SHOSHONE CK NR PRICHARD ID
12134500	SKYKOMISH RIVER NEAR GOLD BAR
Changes from SDC 3 to SDC 4	
08NN015	WEST KETTLE RIVER NEAR MCCULLOCH
Changes from SDC 2 to SDC 3	
10172700	VERNON CREEK NEAR VERNON

Continued on next page

Table B.1 – continued from previous page

ID	Name
10301500	WALKER R NR WABUSKA

Table B.2 Streams changed Snowmelt Domination Categories from 1948 - 1988 period to 1989 - 2009 period), alphabetically ordered

ID	Name
Changes from SDC 4 to SDC 3	
12488500	AMERICAN RIVER NEAR NILE
08MH016	CHILLIWACK R. AT OUTLET OF CHILLIWACK L.
10308200	E F CARSON R BL MARKLEEVILLE C NR MARKLEEVILLECA
15072000	FISH C NR KETCHIKAN AK
9210500	FONTENELLE C NR HERSCHLER RANCH
13337000	LOCHSA RIVER NR LOWELL ID
11264500	MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA
6620000	NORTH PLATTE RIVER NEAR NORTHGATE
11237500	PITMAN C BL TAMARACK C CA
13336500	SELWAY RIVER NR LOWELL ID
10310000	WEST FORK CARSON RIVER AT WOODFORDS
12304500	Yaak River near Troy MT
Changes from SDC 3 to SDC 2	
13168500	BRUNEAU RIVER NR HOT SPRING ID
08GA010	CAPILANO RIVER ABOVE INTAKE
10312000	CARSON RV NR FORT CHURCHILL
13316500	LITTLE SALMON RIVER AT RIGGINS ID
6635000	MEDICINE BOW R AB SEMINOE RESERVOIR
8276500	RIO GRANDE BLW TAOS JUNCTION BRIDGE NEAR TAOS
10343500	SAGEHEN C NR TRUCKEE CA
12186000	SAUK RIVER AB WHITECHUCK RIVER NEAR DARRINGTON
12134500	SKYKOMISH RIVER NEAR GOLD BAR
10336780	TROUT CREEK NR TAHOE VALLEY CALIF
10172700	VERNON CREEK NEAR VERNON

Continued on next page

Table B.2 – continued from previous page

ID	Name
Changes from SDC 2 to SDC 1	
11427700	DUNCAN CYN C NR FRENCH MEADOWS CA
12048000	DUNGENESS RIVER NEAR SEQUIM
9384000	LITTLE COLORADO R ABV LYMAN LAKE NR ST. JOHNS
11206501	MF KAWEAH R NR POTWISHA CAMP(TOTAL FLOW) CA
12411000	NF COEUR D ALENE R AB SHOSHONE CK NR PRICHARD ID
12413000	NF COEUR D ALENE RIVER AT ENAVILLE ID
13073000	PORTNEUF RIVER AT TOPAZ ID
8387000	RIO RUIDOSO AT HOLLYWOOD
9480000	SANTA CRUZ RIVER NEAR LOCHIEL
11189500	SF KERN R NR ONYX CA
10258000	TAHQUITZ C NR PALM SPRINGS CA
Changes from SDC 4 to SDC 2	
10113500	BLACKSMITH FORK AB UP and L CO.S DAM NR HYRUM
10336660	BLACKWOOD C NR TAHOE CITY CA
13185000	BOISE RIVER NR TWIN SPRINGS ID
8380500	GALLINAS CREEK NEAR MONTEZUMA
11266500	MERCED R A POHONO BRIDGE NR YOSEMITE CA
8289000	RIO OJO CALIENTE AT LA MADERA
9408400	SANTA CLARA RIVER NEAR PINE VALLEY
8291000	SANTA CRUZ RIVER NEAR CUNDIYO
12414500	ST JOE RIVER AT CALDER ID
9119000	TOMICHI CREEK AT GUNNISON
Changes from SDC 3 to SDC 1	
11315000	COLE C NR SALT SPRINGS DAM CA
11208001	MARBLE F KAWEAH R (TOTAL FLOW) A POTWISHA CAMP CA
12189500	SAUK RIVER NEAR SAUK
Changes from SDC 4 to SDC 1	
11186001	COMBINED FLOW OF KERN R AND KERN R NO 3 CA

Table B.3 Streams changed Snowmelt Domination Categories from 1948 - 1998 period to 1999 - 2009 period), alphabetically ordered

ID	**Name**
Changes from SDC 4 to SDC 3	
08MH016	CHILLIWACK R. AT OUTLET OF CHILLIWACK L.
08NH115	SULLIVAN CREEK NEAR CANYON
08NJ130	ANDERSON CREEK NEAR NELSON
10131000	CHALK CREEK AT COALVILLE
10310000	WEST FORK CARSON RIVER AT WOODFORDS
11237500	PITMAN C BL TAMARACK C CA
11264500	MERCED R A HAPPY ISLES BRIDGE NR YOSEMITE CA
11266500	MERCED R A POHONO BRIDGE NR YOSEMITE CA
12304500	Yaak River near Troy MT
12370000	Swan River near Bigfork
12462500	WENATCHEE RIVER AT MONITOR
12488500	AMERICAN RIVER NEAR NILE
13186000	SF BOISE RIVER NR FEATHERVILLE ID
13336500	SELWAY RIVER NR LOWELL ID
13337000	LOCHSA RIVER NR LOWELL ID
15072000	FISH C NR KETCHIKAN AK
6620000	NORTH PLATTE RIVER NEAR NORTHGATE
8269000	RIO PUEBLO DE TAOS NEAR TAOS
9210500	FONTENELLE C NR HERSCHLER RANCH
Changes from SDC 3 to SDC 2	
10336780	TROUT CREEK NR TAHOE VALLEY CALIF
11186001	COMBINED FLOW OF KERN R AND KERN R NO 3 CA
12186000	SAUK RIVER AB WHITECHUCK RIVER NEAR DARRINGTON
12189500	SAUK RIVER NEAR SAUK
12414500	ST JOE RIVER AT CALDER ID
13316500	LITTLE SALMON RIVER AT RIGGINS ID
7218000	COYOTE CREEK NEAR GOLONDRINAS
8276500	RIO GRANDE BLW TAOS JUNCTION BRIDGE NEAR TAOS
Changes from SDC 2 to SDC 1	

Continued on next page

Table B.3 – continued from previous page

ID	Name
08GA010	CAPILANO RIVER ABOVE INTAKE
10172200	RED BUTTE CREEK AT FORT DOUGLAS
12048000	DUNGENESS RIVER NEAR SEQUIM
13073000	PORTNEUF RIVER AT TOPAZ ID
8324000	JEMEZ RIVER NEAR JEMEZ
9384000	LITTLE COLORADO R ABV LYMAN LAKE NR ST. JOHNS
9480000	SANTA CRUZ RIVER NEAR LOCHIEL
Changes from SDC 4 to SDC 2	
10113500	BLACKSMITH FORK AB UP and L CO.S DAM NR HYRUM
13185000	BOISE RIVER NR TWIN SPRINGS ID
8289000	RIO OJO CALIENTE AT LA MADERA
8291000	SANTA CRUZ RIVER NEAR CUNDIYO
8380500	GALLINAS CREEK NEAR MONTEZUMA
9119000	TOMICHI CREEK AT GUNNISON
Changes from SDC 3 to SDC 2	
11294000	HIGHLAND C BL SPICER MEADOWS RES CA
Changes from SDC 1 to SDC 2	
10258500	PALM CYN C NR PALM SPRINGS CA
11274500	ORESTIMBA C NR NEWMAN CA
Changes from SDC 2 to SDC 4	
10301500	WALKER R NR WABUSKA
10312000	CARSON RV NR FORT CHURCHILL

Appendix C

CD-Rom

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