Watershed Management and Water Production Study for State of Utah

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A Report for the Utah Governor's
Public Lands Policy Coordination Office

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December 2008

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EXECUTIVE SUMMARY

The amount of water produced from a watershed depends on the climate, soils, geology, land cover, and land use. Precipitation water inputs in the form of rain or snow are partitioned by the watershed into evapotranspiration, runoff, and groundwater recharge. This study examines factors that may impact the production of runoff from Utah watersheds, focusing on factors related to land and watershed management. Specifically, the study looks at how land use changes, such as afforestation, deforestation, agricultural, urban, industrial and mining development, and impact runoff. The scale of interest is regional sub-basins at the USGS cataloging unit 8-digit Hydrologic Unit Code (HUC) scale (http://water.usgs.gov/GIS/huc.html). Twelve 8-digit HUCs in Utah, with an average area of 4500 $km^{2,}$ were selected for this study. Within these sub-basins we identified a total of 39 watersheds draining to USGS streamflow gauges, chosen either from the USGS Hydroclimatic Climatic Data Network of gauges that are minimally impacted by anthropogenic alterations, or to be representative of large areas within the chosen HUCs with long, relatively continuous streamflow records. In each of these watersheds we examined trends in precipitation, temperature, snow, streamflow, and runoff ratio. Runoff ratio is the fraction of precipitation that becomes streamflow. We also examined land use and land cover information for these watersheds from the national land cover dataset, southwest regional GAP analyses and the Utah division of water resources water-related land use inventory.

The most consistent trend noted was in temperature, which is increasing. We did not note any significant trends in precipitation. Fourteen of the 39 watersheds examined had significant decreasing trends in streamflow and runoff ratio. We were unable to find definitive causes for these streamflow and runoff ratio trends, though we do have indications that some of them are associated with human development, storage in reservoirs, and land cover and land use changes.

In analysis of the land cover data we found that unequivocal interpretation of land cover changes was confounded by differences in methodology and technology used to determine land cover over time. We were, consequently, unable to derive relationships from the data as to how land cover and land use affect water production.

So as to provide some information helpful for land management policy making and economic analyses, we developed a water balance approach that quantifies sensitivity of runoff production to changes in land cover, based on differences in evapotranspiration from different land cover types. The coefficients that quantify the potential evapotranspiration from each land cover type in this analysis are based on our judgment and information from the literature. In coming up with these coefficients we also endeavored to reconcile them with precipitation, streamflow, and runoff ratio data for the Utah study watersheds. This water balance approach provides predictions of how water production from these Utah watersheds may change with land cover changes. By considering a range of water balance model parameters, we provide water balance-derived bounds on how streamflow could change given land cover changes. However, we caution that in the use of these results, the sensitivities depend directly upon the coefficients that quantify the potential evapotranspiration from each land cover type. This represents a fairly gross simplification. In semi-arid settings, the vegetation water use is often limited by water availability, rather than potential evapotranspiration, and differences in water yield may relate more to factors such as the timing and rate of water inputs (precipitation intensity and snowmelt). Vegetation also depends strongly on topographic setting, due to factors such as elevation, aspect, and solar radiation exposure. Changes in the proportioning of land cover in a watershed, therefore, should consider the control that topographic setting has on land cover.

Economic considerations associated with changes in water production were also examined. Value was estimated using two approaches: 1) the price for leases and sales of water rights, and 2) using "shadow values" derived from economic models based on the increasing profitability of water users as water availability increases (or decreases). In general, we noted that irrigated agriculture was responsible for around 80% of water diversions, but that municipal and industrial (M&I) water had higher prices than water for irrigated agriculture. Purchase price for irrigated agriculture in this region has ranged from $25 to $400 per acre foot. Purchase price for M&I water has ranged from $300 to $25,000 per acre foot. Shadow value estimates of the value of water to irrigated agriculture ranged from $300 to $1,500 per acre foot. These figures indicate that, while the value of water is time and place dependent, and it is difficult to generalize about the value of the changes in water production that, in general, the economic value of additional water in irrigation is relatively low, but that water for M&I is generally of higher economic value, which suggests that increases in water production from watersheds serving urban areas are likely to have relatively high returns, while water increases used for irrigation use will have relatively low returns.

INTRODUCTION

Watershed development and management require an understanding of basic hydrologic processes; i.e., water balance components and how they affect each other. Current concerns that are motivating the study of water production in arid regions include climate change, impacts of land management, and management of water supplies. Changes in land use or management systems result in complex interactions of various processes that in turn affect runoff. The objective of this study was to address the broad question of how watershed management and land use impacts water production from watersheds in Utah. To address this general question, the following specific questions were considered:

1. What is the water input to Utah watersheds?
2. What is the natural runoff from Utah watersheds?
3. How does land use and management impact runoff?
4. What is the economic value or impact of changes in water availability resulting from land use and management of watersheds?

LITERATURE REVIEW

1. Watershed management, land cover, land use, and climate change may have both immediate and long-lasting impacts on terrestrial hydrology, altering the balance between rainfall and evapotranspiration and the resultant runoff. The impact of vegetation cover change on the hydrological cycle in the past has been studied through paired catchments. Paired catchments have helped determine the magnitude of water yield changes in response to changes in vegetation. The main categories of paired catchment studies are afforestation experiments, deforestation experiments, re-growth experiments, and forest conversion experiments. These field experiments quantify the consequences of land use changes on annual runoff, flood, and low flow response and water quality. Hibbert (1967)

reviewed 39 studies of the effect of altering forest cover on water yield and concluded that the reduction of forest cover increases water yield and, in contrast, the establishment of forest cover on sparsely vegetated land decreases water yield. He indicated a practical upper limit of yield increase of 4.5 mm (0.18 in) per year for each percentage reduction in forest cover, although the increases were considerably less in the western United States (Colorado) data he reviewed. Bosch and Hewlett (1982) compiled data from 94 catchment experiments (watersheds from the United States, New Zealand, Japan, and Australia, including one, Beaver Creek, in Utah) that were essentially consistent with Hibbert's findings. Bosch and Hewlett (1982) concluded that 'Coniferous forest, Deciduous hardwood, Bush, and Grass cover have (in that order) a decreasing influence on water yield from the source areas in which these covers are manipulated'. They noted that, on average, there is approximately 40 mm (1.6 in) increase in annual water yield for 10% reduction in Coniferous forest cover. For Deciduous hardwood forest they found on average 25 mm (1 in) increase in annual water yield for 10% reduction in forest cover, while 10% reduction of bush and grassland generates on average a 10 mm (0.4 in) water yield increase.

Stednick (1996) assessed water yield changes after vegetation removal by analyzing 95 catchments studies in the United States with one catchment study in Utah (Chicken Creek, UT, Johnston, 1984). Stednick (1996) noted that in the Rocky Mountain/Inland Intermountain region studies, the annual water yield increase, when 50% of the catchment was harvested, ranged from 25 mm (1 in) to 250 mm (10 in). For complete harvesting (100%), the annual water yield increase ranged from zero to more than 350 mm (14 in). The regression that Stednick fit to data from the Rocky Mountain/Inland Intermountain region had a slope indicating 9.4 mm (0.4 in) yield increase per 10% of area harvested. Stednick indicated that streamflow variation in response to vegetation conversion depends both on the region's annual precipitation and on the precipitation for the year under treatment. Johnston (1984) reported results from a paired catchment study in Chicken Creek watershed in the headwaters of Farmington Canyon about 14 miles northeast of Salt Lake City. Johnston reported that removing aspen from 13% of the watershed had no significant effect on streamflow yield. However, Stednick (1996) included Johnston's results in his study and reported a yield rate of 24.5 mm (1 in) per 10% of area harvested. Troendle et al., (2001) demonstrated that water yield augmentation technology, developed from research on small experimental watersheds, would work well at an operational scale. After removal of forest from 23.7% of Coon Creek watershed, a 1673 ha catchment on the Upper East Fork of the Encampment River, Wyoming, seasonal streamflow (April–October) increased on an average 76 mm (3 in) for the first five years after harvest.

Another approach for examining the effect of land use changes on a watershed's hydrological response is to use physically based and spatially distributed ecosystems, land surface and hydrological models (Abbott et al., 1986; Bathurst et al., 2004 ; Bathurst and O'Connell, 1992; Calder et al., 2003; Refsgaard, 1987; VanShaar et al., 2002). VanShaar et al., (2002) selected four catchments within the United States portion of the Columbia River Basin (ranging from 27 to 1033 km^2) to simulate the hydrological effects of changes in land cover using the DHSVM model (Wigmosta and Lettenmaier, 1999; Wigmosta et al., 1994). VanShaar et al., (2002) indicated that lower leaf area, i.e., decreased vegetation extent, has led to increased snow accumulation, increased streamflow and reduced evapotranspiration. They also noted that streamflow changes are greatest during spring snowmelt runoff, and evaporation changes are greatest when soils are more moist (i.e., spring and early summer). Calder et al., (2003) examined different types of vegetation and their possible impacts on water resources due to a proposed doubling of woodland area within the United Kingdom by the year 2045. Observations in grass, heath, oak, and pine were used with the water use model HYLUC, (Calder, 2003), to derive predictions of the impacts of different vegetation types on recharge at Clipstone Forest and Nottinghamshire. The results from this study, which was conducted in a relatively dry region of Britain, demonstrated the extreme sensitivity of recharge plus runoff to vegetation covers. Calder et al., (2003) found that oak woodland is predicted to have a significant impact through its reduction of recharge plus runoff by almost half when compared to grassland.

Land cover changes often impact evapotranspiration which in turn affects runoff. Extensive field work has been done in the United Kingdom to observe the effects of land use changes on runoff through evapotranspiration changes by Calder (1986; 1993; 1998; 2003) and Calder et al., (2003). These studies have developed many models to assess the effect of afforestation and deforestation on water production. The approach taken to develop annual evaporation models appropriate to assess the effects of land cover and land use changes on runoff involved partitioning evaporation into two components, transpiration and interception. Interception was estimated by relation to the amount and duration of precipitation, while transpiration was determined in relation to a reference evaporation estimate (Calder, 1990). Estimating the transpiration fraction, β, which is the ratio between the actual annual evaporation and annual reference potential transpiration estimate for different types of vegetation has been well tested in many experiments within the United Kingdom (Calder, 1990) .

Changes in water yield due to land cover changes can be addressed by considering variability in climate and water balance components. The water balance components of a watershed are: 1) precipitation water input which is comprised of snow and rain detonated as, P; 2) the streamflow that leaves the watershed, Q; 3) evapotranspiration that leaves the watershed, E; 4) and change in storage water within the watershed. Milly (1994) hypothesized that the long-term water balance is determined only by the local interaction of fluctuating water supply and demand mediated by the water storage in the soil. This hypothesis uses the concept of water-holding capacity to summarize the role played by the land-water environment in hydrologic response, while ignoring many of the details of soil water flow, thereby providing a practical way to model the system when information on detailed variability of hydrological processes is limited. Milly (1994) suggested that partitioning precipitation into runoff and evapotranspiration is determined by seven dimensionless numbers. These numbers are the ratio of annual potential evapotranspiration to annual precipitation (index of dryness), the ratio of water-holding capacity to annual mean precipitation, the mean number of precipitation events per year, the ratio of seasonal fluctuations to annual means of precipitation, storm arrival rate, potential evapotranspiration, and the spatial variability of water-holding capacity.

Budyko (1974) presented a physical, practical, and meaningful explanation for climate variability through the climate index ratio which is the ratio between mean annual evaporation and mean annual precipitation (E/P). A low climate index ratio means a wet climate while a high climate index ratio means a dry climate. The Budyko (1974) curve is suggested to describe the geographical variation of E/P as a function of the ratio of the mean annual potential or reference evaporation (surrogate for the net radiant energy) and annual precipitation R/P, and serves as a practical tool available to explain some of the variability seen in hydrological processes. Spatial variability of the relationship between annual runoff and annual precipitation is credited to L'vovich (1979), who explained the geographical variations of the relationship between annual runoff and annual precipitation by presenting different climates, soils, and vegetation, including the way that vegetation adapts to water stress (leaf shedding & deep rooting) and how they would affect the spatial variability of the relationship between runoff and precipitation. Sivapalan (2005) surmised that runoff variability predictors include climate, catchment area and shape, river network, soil properties, geology, topography, and vegetation.

A considerable body of work has examined trends and changes in hydrological variables in the western United States, where streamflow is driven by snowmelt. Cayan et al., (2001) documented the early onset of spring in the western United States by examining changes in the blooming of plants (lilac and honeysuckle bushes) and the timing of spring snowmelt pulses. McCabe and Wolock (2002) observed a step increase in streamflow in the conterminous United States over the period 1941-99, with pronounced increases in the eastern United States after 1970. Aguado et al., (1992), and Dettinger and Cayan (1995) reported that increasing winter temperature, as observed in several parts of the western United States, reduces the amount of snow in a basin (e.g., more precipitation falling as rain than snow). Mote (2003) studied trends of Snow Water Equivalent (SWE) in the Pacific Northwest and observed strong declines in April 1 SWE, in spite of increases in precipitation, which is consistent with an increase in spring temperature. Regonda et al., (2005) analyzed streamflow, snowpack, temperature, and precipitation in snowmelt-dominated river basins in the western United States. They found that significant declines in monthly SWE, and increases in winter precipitation are evident for many stations in the western United States. The largest declines are occurring in the Pacific Northwest, the northern parts of Idaho, Utah, Wyoming, and the Sierra Nevada region. In addition, they found an indication of an advance in the timing of peak spring season flows over the past 50 years. They argued that the trends in SWE can be influenced by both temperature and precipitation. They also noted that during recent decades more precipitation is coming as rain rather than snow. Mote et al., (2005) extended the Mote (2003) study by incorporating the entire western United States from the Continental Divide to the Pacific, and from central British Columbia, Canada, south to southern Arizona and New Mexico. In addition, they augmented the long-term monthly manual observations of snow with a more recent dataset of daily-telemetered snow observations. Moreover, they corroborate the analysis of snow data using a hydrological model (the Variable Infiltration Capacity model (VIC), Liang et al., 1994) with observed daily temperature and precipitation data. Their findings are generally consistent with the earlier work reviewed above. Overall, this body of work shows that widespread declines in spring time SWE have occurred in much of the North American West over the period 1925-2000, especially since mid-century (Aguado et al., 1992; Cayan et al., 2001; Mote, 2003; Regonda et al., 2005).

Summarizing the discussion above, the study of land cover changes impact on streamflow has been addressed by analyzing observations in paired catchments, and using physically based and conceptual models. Runoff variability predictors include climate, catchment area and shape, river network, soil properties, geology, topography, and vegetation. Streamflow increase after vegetation removal has been addressed in many studies in the Rocky Mountain region. Notable among these studies are Wagon Wheel Gap, Fool Creek, Deadhorse Creek, and Fraser Experimental Forest (FEF) in central Colorado (Bates and Henry, 1928; Troendle and King, 1985; Troendle and King, 1987; Troendle and Olsen, 1994; Troendle and Reuss, 1997; Van Haveren, 1988). Reduction of forest cover decreases evapotranspiration which increases water yield, while in contrast the establishment of forest cover on sparsely vegetated land decreases water yield. However, there are studies that indicate increased snow accumulation in areas with lower vegetation density, which may counter this effect. With respect to water availability in the western United States, significant declines in monthly snow water equivalent (SWE) and increases in winter rain rather than snow are evident for many watersheds. The largest declines in SWE are in the Pacific Northwest region, the northern parts of Idaho, Utah, Wyoming, and the Sierra Nevada region. In addition, there is indication of an advance in the timing of peak spring season flows over the past 50 years.

DATA

Streamflow Data

Some 39 watersheds were selected across Utah to study the trends in and sensitivity of streamflow (Q) to land cover changes. The hydrological team at the State Engineer office provided a list of USGS cataloging unit sub-basins (HUC 8) that are of interest to the state. Within these sub-basins we identified a total of 39 watersheds draining to USGS streamflow gauges, chosen either from the USGS Hydroclimatic Climatic Data Network (HCDN) (http://pubs.usgs.gov/wri/wri934076/1st_page.html) of gauges that are minimally impacted by anthropogenic alterations, or to be representative of large areas within the chosen HUCs with long, relatively continuous streamflow records. The delineated study watersheds are mapped in Figure 1 and listed in Table 1 that gives the USGS streamflow station at the outlet as well as drainage area for each watershed. The 4-digit Watershed ID in the first column of this table is used to identify watersheds in this study. HCDN stream gauges (Slack et al., 1993), are stream gauges deemed to be relatively free of controls, diversion, or human impacts, and are, therefore, suitable for the study of surface water conditions and climate studies. Five HCDN stations were used in this study. The streamflow dataset for the remaining gauges was retrieved from USGS surface water data for Utah website (http://nwis.waterdata.usgs.gov/ut/nwis/sw).

Precipitation and Temperature Data

Long-term precipitation (P) and temperature (T) data were obtained from the Surface Water Modeling group at the University of Washington (http://www.hydro.washington.edu/Lettenmaier/Data/gridded/index_hamlet.html). The development of this gridded dataset is described by Hamlet and Lettenmaier (2005). This dataset includes daily 1/8-degree resolution gridded meteorological data for 1 Jan 1915–31 Dec 2003, grouped into the Northwest and Columbia, California, Great Basin, and Colorado River regions. We extracted the data for our study watersheds from the datasets for the Great Basin and Colorado River regions.

The Parameter-elevation Regressions on Independent Slopes Model (PRISM) is an analytical method that uses point data, a digital elevation model, and other spatial datasets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation, temperature, and dew point (http://www.prism.oregonstate.edu/). The PRISM Group was established at Oregon State University (OSU) to provide spatial climate research datasets. Figure 2 gives the 30-year (1971–2000) average annual precipitation over the State of Utah retrieved from the PRISM Group website. This gives a general sense of the variability of mean annual precipitation across the study watersheds. When these values are aggregated over the study watersheds, annual precipitation averages range about 700 mm (28 in) in the highest elevation watersheds to about 180 mm (7 in) in the drier watersheds.

Snow

Snow water equivalent (SWE) datasets were obtained form the Natural Resources Conservation Service (NRCS) automated SNOTEL system (http://www.wcc.nrcs.usda.gov/snotel/Utah/utah.html). All SNOTEL sites in the 39 study watersheds were used in this study. An average time series of maximum and April 1 SWE values in each watershed was calculated by averaging the individual SNOTEL station maximum and April 1 values. These averages were adjusted to account for bias due to different lengths of record at sites that have differing average SWE. This adjustment procedure from Mohammed (2006) is given in Appendix 1.

Snow-covered area data were retrieved from the National Operational Hydrologic Remote Sensing Center (NOHRSC) (http://www.nohrsc.noaa.gov/). The number of snow-covered days within each year—when the percentage of the snow-covered area is more than 50% of the watershed—was used to examine snow covered area trends.

Land Cover and Land Use

We investigated land cover and land use changes using multiple data sources: the Southwest Regional Gap Analysis Project (SWReGAP) (http://earth.gis.usu.edu/landcover.html), the GAP Analysis Program datasets (http://gapanalysis.nbii.gov/portal/server.pt), the National Land Cover Dataset (NLCD) (http://gisdata.usgs.net/website/MRLC/viewer.php), and water-related land use files from the Utah Division of Water Resources. The SWReGAP is a multi–institutional cooperative effort coordinated by the U.S. Geological Survey Gap Analysis Program. The primary objective of the SWReGAP is to use a coordinated mapping approach to create detailed, seamless GIS maps of land cover, all native terrestrial vertebrate species, land stewardship, and management status for the five-state region encompassing Arizona, Colorado, Nevada, New Mexico, and Utah (Lowry et al., 2005). The SWReGAP product gives the land cover and land use characteristics in 2004 while the GAP product is for 1995.

TREND AND DATA ANALYSIS

Streamflow and precipitation trends were analyzed for all the study watersheds. These are presented in a series of figures (Figure 3.1 through Figure 3.39). Data was aggregated for all the water years (October to September) of record for each watershed. In each of these figures, the first panel plots per unit area streamflow (Q/A) versus precipitation. Q/A is also referred to as runoff. The units used for both precipitation and runoff are meters as these are volume per unit area or depth quantities. Different symbols are used to partition the data into three time periods: 1916–1979, 1980–1995, and 1995–2003 so as to see whether the runoff production function may have changed over time. The second panel gives the time series of per unit area streamflow (Q/A). The third panel gives the time series of annual runoff ratio (Q/AP). This is the ratio of annual per unit area streamflow to precipitation and quantifies the fraction of the input precipitation that leaves the watershed as streamflow. To the extent that streamflow represents usable water, runoff ratio quantifies the water that is "produced" in the watershed as a fraction of precipitation. The fourth panel gives the time series of precipitation. Trends in these figures are visualized using LOWESS and evaluated using the default parameters in the R software package (Cleveland, 1981; R Development Core Team, 2008).

Mann Kendall trend analysis (Helsel and Hirsch, 2002, chapter 8 & 12) was used to examine whether any trends were statistically significant. No trends in precipitation were found to be statistically significant (results not shown). Table 2 gives trend analysis results for the runoff ratio (Q/AP). This table includes the mean annual runoff ratio, μ, the annual standard deviation, σ, the coefficient of variation CV, the lag 1 correlation $\rho1$, the Kendall's tau correlation coefficient τ, as well as the p-value associated with the Mann Kendall test. Table 2 shows that there are 14 stations with significant ($p < 0.05$) decreasing trends in runoff ratio. Five of these are highly significant ($p < 0.001$), namely Weber River near Plain City, Virgin River at Virgin, Rock Creek near Mountain Home, Duchesne River near Tabiona and Sevier River at Hatch. There is one station, the Jordan River and a surplus canal at Salt Lake City that shows a highly significant increasing trend. This station is highly impacted by managed releases from Utah Lake.

SNOTEL Snow Water Equivalent was averaged across each watershed using the bias correction procedure described in the appendix. Figure 4 and Figure 5 give maps of the 2006 maximum and April 1 snow water equivalent as an illustration of the spatial pattern of snow across the study watersheds. Snow trend analyses are presented in Figure 6.1 through Figure 6.7, for the watersheds with significant snow. Panels in these figures give the maximum April 1 and the mean snow water equivalent (calculated over 12 months) time series as well as the number of days with snow-covered area more than 50% from the NOHRSC data. These figures show a declining trend of SWE represented in maximum April 1 and mean across most of the watersheds studied. This is consistent with the findings given in the literature review of widespread declines in SWE across much of the North American West over the period 1925–2000, especially since mid-century. However we should caution that the interpretation of trends from SNOTEL data suffers from the fact that records are short and many SNOTEL stations are impacted by other external influences (Julander and Bricco, 2006).

Air temperature trend analyses are presented in Figure 7.1 through Figure 7.39. These use the University of Washington gridded air temperature data averaged for each watershed and then averaged for water year (October to September) in panel 1 and for three "seasons" in panels 2 to 4, (Winter: November, December, January, and February; Spring: March, April, May, and June; and Summer: July, August, September, and October). These graphs show that there is an increasing air temperature trend in most of the watersheds studied.

Land cover information from the National Land Cover Dataset (NLCD) for 1992 and 2001 was summarized for each study watershed. However when we started looking at changes we found that different land cover classifications had been used in each dataset, and upon deeper investigation noted that the NLCD 1992 and NLCD 2001 are not designed for direct comparison (Homer et al., 2007, and http://www.epa.gov/mrlc/change.html). This difference in methods used to produce nationally available land cover datasets makes them unsuitable for detecting the change in land cover and land use. Work is reportedly underway in the federal agencies involved with land cover monitoring (USGS, EPA, NOAA) to resolve these differences and produce national data appropriate for change monitoring (http://www.epa.gov/mrlc/nlcd-2006.html). Such data were, however, not available at the time of this study.

In order to detect the change in land cover and land use between 1995 and 2004, we modified the 1995 GAP classification to be consistent with the 2004 SWReGAP classification using a cross bridge classification analysis provided by the Utah State University RS/GIS laboratory (Ramsey, personal communication, 2008). This modification was necessary because the classification schemes in the two products are not the same (SWReGAP 2004 classes are different from 1995 GAP classes). Table 3 groups land cover into five broad categories used in this study and presents the area percentage of each for the study watersheds for 1995 & 2004 from the modified 1995 GAP and 2004 SWReGAP studies. This serves as a preliminary analysis of land cover and land use change in the study watersheds within the State of Utah. Despite using the modified 1995 GAP, we still have some concerns as to how many of the changes indicated in this table are real, versus methodological differences. Nevertheless we attempted a broad classification of the changes and noted that there appear to be four predominant change classes:

1. Increasing Barren area – 7 watersheds (1401, 1501, 1800, 2100, 2200, 2201, 2202).
2. Increasing Deciduous Forest, mostly together with a reduction in Range/Shrub/Other – 13 watersheds (1201, 1202, 1203, 1204, 1301, 1302, 1400, 1403, 1700, 1803, 1804, 2000, 2202)
3. Decreasing Deciduous Forest – 4 watersheds (1102, 1900, 1901, 1902)
4. Decreasing Coniferous Forest, mostly to Range/Shrub/Other and some to Deciduous Forest – 8 watersheds (1100, 1500, 1600, 2101, 2102, 2103, 2104, 2105, 2202)

Note that watershed 2202 appears in multiple categories.

Comparing these change classes to the runoff ratio trends identified in Table 2, we note that four of the seven watersheds with increasing Barren area (1800, 2200, 2201, 2202) have decreasing runoff trends. Four of the 13 watersheds with increasing deciduous have decreasing runoff trends (1201, 1301, 1803, 2202), and four of the nine watersheds with decreasing Coniferous forest have decreasing runoff trends (2101, 2104, 2105, 2202). There are also four watersheds with runoff trends that are not identified as having land use changes (1200, 1402, 1802, 2001). These patterns are sometimes counter to hydrologic understanding (decreasing runoff with decreasing Coniferous forest), and there are a comparable number of watersheds in each land cover change class that do not have significant runoff ratio trends, compared to those that do. These patterns, therefore, do not appear to have a consistency that could allow them to be used for prediction.

Table 4 gives the water-related land use from the Utah Division of Water Resources for the study of watersheds. The table shows irrigated agricultural lands, non-irrigated agricultural lands, residential urban areas, riparian lands, other urban lands (not residential which includes commercial, industrial, etc), and areas of open water (reservoirs). The columns A_{86}, A_{96} etc. give the area associated with the indicated land use in km^2 in the year corresponding to the subscript. These do not add up to the total area of the watershed, because water-related land use only covers a portion (sometimes a small portion) of each watershed. Urban growth can be seen from the data in Table 4 in watersheds where the areas designated as RES (residential) or URB (other urban) have increased. This is most notable in the Weber River watershed where urban area has doubled, but this table confirms that urban growth is occurring across the state. In Table 4, increased areas designated as open water occur in a majority of the study watersheds. This we take to be indicative of water development such as diversions and reservoirs that are likely to influence streamflow and may be responsible for some of the streamflow trends observed.

Water Balance Sensitivity Model: A water balance sensitivity model was developed to quantify the sensitivity of runoff production to changes in land cover based on differences in evapotranspiration from different land cover types. The approach assumes that potential or reference evapotranspiration is a function of land cover type, and that relative differences can be quantified by a set of land cover coefficients for reference evapotranspiration from each land cover type. The set of coefficients used in this study was based upon our judgment but with reference to the literature. The average water balance partitioning function introduced by Budyko (1974) was used to estimate the basin average reference evapotranspiration within a watershed. Then, when land cover is changed, this reference evapotranspiration is adjusted based on the land cover reference evapotranspiration coefficients. This is fed back in to the Budyko curve to estimate actual basin average evapotranspiration and streamflow for the changed conditions. This procedure was used to estimate the sensitivity of streamflow from each watershed to change in each land cover type.

The water balance of a watershed may be stated as:

$$P = q + E + \Delta S \quad (1)$$

where, P is the precipitation input, q is the runoff that leaves the watershed, E is the evaporation and transpiration that leaves the watershed and ΔS is the change in storage of water within the watershed. In this equation we have used the lowercase notation q to represent runoff, i.e., streamflow on a per-unit area basis, to keep this distinct from Q used earlier as a volume. These are related through, $q=Q/A$. All quantities in equation (1) are expressed in depth units. Equation (1) quantifies the proportioning of precipitation into runoff, evaporation, and storage. Over long-time scales the change in storage may often be neglected, such as if the time scale is several years and there is no net increase or decrease in subsurface or reservoir storage during this period or if the equation is interpreted as quantifying the ultimate disposition of water input. Then this equation can be written as: $q = P - E$. (2)

This expresses the fact that runoff is the difference between P and E and that both variability in P and E impact runoff. Land use and watershed management changes have some direct impacts on runoff, q, but the most significant impacts of land use and watershed management are often on evaporation and transpiration, namely E. For example, reduction of forest cover is generally presumed to reduce E, while increases in forest cover increase E (Calder, 1993). Implicit here is the assumption that the land cover that replaces forests demands less water.

Budyko (1974) presented a semi-empirical expression for average water balance partitioning as a function of the relative magnitudes of water and energy supply rates. He stated the relation as:

$$\overline{E}/\overline{P} = \varphi\left(\overline{R}/\overline{P}\right) (3)$$

where, $\overline{E}$ is the average annual evaporation, $\overline{P}$ is the average annual precipitation, $\overline{R}$ is the mean annual potential or reference evapotranspiration (surrogate for the net radiant energy), and φ is a general partitioning function. Budyko (1974) suggested the following partitioning function, φ, based upon best fitting to data as:

$$\varphi(x) = \varphi_B(x) \equiv \left[x(\tanh(x^{-1}))(1 - \cosh(x) + \sinh(x))\right]^{1/2} (4)$$

Based upon the identification of net radiation as a control on evaporation under conditions of available water supply, many relationships have been proposed similar to equation (4) (Brutsaert, 1982; Choudhury, 1999). Choudhury (1999) presented a family of functions that can be used to describe $\varphi(x)$ as:

$$\varphi(x) = \varphi_v(x) = \left[1 + x^{-v}\right]^{-1/v} \quad (5)$$

where, v is a curve parameter. Milly and Dunne (2002) refer to equation (5) as the generalized Turc-Pike relation (Pike, 1964; Turc, 1953). Moreover, Milly and Dunne indicate that the generalized Turc-Pike relation closely approximates the Budyko relation, equation (4), when $v = 2$.

The approach presented in this study has the following assumptions:

The potential evapotranspiration from each specific land cover type, E_{plc}, is a function of the reference evapotranspiration and can be written as: $E_{plc}=R^{*}\times r_{lc}$(6)

where R^{*} is the regional reference evapotranspiration based on energy available, and r_{lc} is the land cover relative potential evapotranspiration coefficient.

The watershed average land cover adjusted reference evapotranspiration, R, is calculated as:

$$R = \sum E_{plc} P_{lc} = R^{*} \sum P_{lc} r_{lc} \quad (7)$$

where, P_{lc} is the proportion of land cover area for each specific land cover type.

The generalized Budyko function is taken to be applicable at watershed scale resulting in

$$E / P = \varphi(R / P)$$

Thus, changes in land cover result in changes in R which through this equation results in changes in E and runoff, q = P-E.

Table 5 shows the values of the relative potential evapotranspiration coefficients, r_{lc}, for land cover types used in this study. These coefficients represent our judgment based upon reading the literature (e.g. Calder, 1993; Dingman, 2002; Federer et al., 1996) as to the differences in potential evapotranspiration for different land covers. In arriving at the coefficients used in Table 5, we considered reported values for leaf conductance, leaf area index, albedo, vegetation height, and vegetation density. These coefficients are the principle determinants of the differences in runoff that we calculate.

The approach taken in this study to quantify the sensitivity of streamflow to land cover changes within a watershed can be expressed through following steps:

I. From annual average estimates of precipitation, P, and runoff, q, we estimate the annual actual evapotranspiration through equation (2).

II. Using the actual evapotranspiration ratio, i.e. E/P, we find R, the watershed average land cover adjusted reference evapotranspiration, by solving equation (5).

III. The regional reference evapotranspiration, R^*, is then estimated from

$$R^* = R / \sum P_{lc} r_{lc} . \quad (8)$$

IV. For new land cover proportions, P'_{lc}, the new watershed average land cover adjusted reference evapotranspiration is then calculated as:

$$R' = R^* \sum P'_{lc} \times r_{lc} = R \frac{\sum P'_{lc} \times r_{lc}}{\sum P_{lc} \times r_{lc}} \quad (9)$$

This assumes that R^* remains the same and that R is adjusted based on the coefficients r_{lc} and changing P_{lc}. The second expression of (9) above bypasses equation (8).

V. The new average annual actual evapotranspiration, E', is then found by solving equation (5) with R'. In other words, $E'/P = \varphi(R'/P)$.

VI. A new estimate of streamflow, q', is found through solving the mass balance equation (equation 2).

Sensitivity Results

Table 6 gives water balance estimates for streamflow, precipitation, and evapotranspiration for the study watersheds. Q/A and P are based upon data described above, and minimum, mean, median, and maximum across the years of record are reported (in units of meters). The actual evapotranspiration column is calculated from mass balance using the mean P and Q/A. The potential evapotranspiration is the watershed average land cover adjusted reference evapotranspiration inferred from the Budyko (1974) relation with ν=2 using mean P and Q/A.

We evaluated the sensitivity of streamflow to land cover change for each watershed for some potential land cover changes of interest. We also used a range of Budyko curve parameters (ν=1.5, 2, 10) to explore the sensitivity of the findings to this parameter. We evaluated the sensitivity to changes in a specific land cover type by increasing it and reducing some other land cover types in proportion to their land cover fractions while holding remaining land cover proportions constant.

We found that the changes in streamflow were, in general, close to being linearly proportional to the changes in land cover, so have expressed sensitivity in terms of a derivative that was evaluated numerically using a 10% land cover fraction increase. For example, for a watershed with 40% of a particular land cover type, the sensitivity to change of that specific land cover type would be calculated as

$$S^{lc=i}_{\nu=j} = \frac{\text{Streamflow}_{50\%} - \text{Streamflow}_{40\%}}{0.5 - 0.4} \quad (10)$$

A decrease in streamflow is reflected in a negative sensitivity coefficient. Streamflow in units of acre-ft/mi^2/yr was used, so the sensitivity values reported are acre-ft/mi^2/yr per fraction change in land cover proportion.

In Table 7 we report the sensitivity to changes in the proportion of Coniferous land cover holding the proportion of Agricultural land cover constant and allowing other land cover proportions to change. This was done twice, first for the relative potential evapotranspiration coefficients in Table 5, and then for switched Coniferous and Deciduous land covers relative potential evapotranspiration coefficients. The relative potential evapotranspiration coefficients used are given in the header to the corresponding columns in Table 7. Switching the Coniferous and Deciduous coefficients was done because, although in Table 5 we have indicated greater water use from Coniferous forests, there have been some studies (LaMalfa, 2007) that suggest higher water use from Aspen. We wanted to evaluate the sensitivity of water production to this question.

In Table 8 we report the sensitivity to changes in the proportion of Range/Shrub/Other land cover. This was done first allowing all other land cover proportions to adjust, and for both the Coniferous and Deciduous coefficients from Table 5 and switched. Then we considered Range/Shrub/Other land cover being replaced by Forest (Deciduous and Coniferous land cover types), holding the proportion of Agricultural and Barren land covers constant, again also presenting results for coefficients from Table 5 and switched Coniferous and Deciduous land covers relative potential evapotranspiration coefficients.

Examination of Table 7 and Table 8 indicates that increasing Coniferous forests decreases streamflow, while increasing Range/Shrub/Other increases streamflow. The reduction in streamflow with increasing Coniferous forest, regardless of whether the relative potential evapotranspiration coefficient for Deciduous or Coniferous is greater, is due to the generally large area of Range/Shrub/Other that is displaced and has smaller water use in this sensitivity model. Streamflow reductions are calculated to be larger for the case when the relative potential evapotranspiration coefficient for Coniferous is greater. The increase in streamflow with increasing Range/Shrub/Other is similarly due to the generally large area of Forest (either Deciduous or Coniferous) that is displaced and has greater water use in this sensitivity model. Using the coefficients calculated in Table 7 for the set of relative potential evapotranspiration coefficients with Coniferous greater than Deciduous (Table 5), and $\nu=2$, we found that reducing 50% of the Coniferous area present in the study watersheds, resulted in streamflow increases that ranged from 1 to 80 ac–ft/mi^2/year. Using the coefficients in Table 8 for the set of relative potential evapotranspiration coefficients with Coniferous greater than Deciduous (Table 5), and $\nu=2$, we found that 50% reduction of the area present that is Range/Shrub/Others with this area transitioning to forest results in streamflow decreases that ranged from 8 to 78 ac–ft/mi^2/year.

Five watersheds were selected to show the streamflow sensitivity to changes in Coniferous and Range/Shrub/Other land cover types. From southern Utah we selected the Virgin River near Virgin watershed (watershed_ID = 1800); from central Utah, we selected the Sevier River at Hatch (watershed_ID = 2201); from the Uintah Basin, we selected the Duchesne River near Tabiona (watershed_ID = 2104); from the Wasatch Front, we selected the Red Butte Creek at Fort Douglas near Salt Lake City (watershed_ID = 2000); and from northern Utah, we selected the Blacksmith Fork near Hyrum watershed (watershed_ID = 1900). Figure 8.1 to Figure 8.30 give streamflow sensitivity in the above watersheds for changes in Coniferous and Range/Shrub/Other land covers. Figure 8.1 to Figure 8.5 give the transition of Coniferous land cover to Barren, Range/Shrub/Other, and Deciduous with the fraction that is Agriculture held fixed and relative evapotranspiration coefficient for Coniferous greater than Deciduous (Table 5). Figure 8.6 to Figure 8.10 give the transition of Coniferous land cover to Barren, Range/Shrub/Other, and

Deciduous with Agriculture fixed and relative evapotranspiration coefficient for Deciduous greater than Coniferous (i.e., switched from Table 5). Figure 8.11 to Figure 8.15 give the transition of Range/Shrub/Other land cover to Barren, Coniferous, Deciduous, and Agriculture with relative evapotranspiration coefficient for Coniferous greater than Deciduous. Figure 8.16 to Figure 8.20 give the transition of Range/Shrub/Other land cover to Barren, Coniferous, Deciduous, and Agriculture with relative evapotranspiration coefficient for Deciduous greater than Coniferous. Figure 8.21 to Figure 8.25 give the transition of Range/Shrub/Other land cover to Coniferous/Deciduous only; i.e., Agriculture and Barren are fixed with relative evapotranspiration coefficient for Coniferous greater than Deciduous. Figure 8.26 to Figure 8.30 give the transition of Range/Shrub/Other land cover to Coniferous/Deciduous only; i.e., Agriculture and Barren are fixed with relative evapotranspiration coefficient for Deciduous greater than Coniferous. The hatched area shown in the sensitivity of streamflow figures, expressed in streamflow per unit area, q (ac-ft/mi^2/yr), represents the family of solutions to the Choudhury (1999) partitioning function, i.e. from $\nu = 1.5$ to $\nu = 10$ where ν is the curve parameter. The red line, i.e. $\nu = 2$, represents the Budyko semi-empirical expression for the average water balance partitioning function. The slopes shown in Figure 8.1 to Figure 8.30 give the sensitivity of runoff to change in percentage land cover (equation 10) for $\nu=2$ at the existing land cover percentages, with ± range indicated corresponding to ν in the range from 1.5 to 10. These figures show how with this model increasing Coniferous areas leads to reducing streamflow while increasing Range/Shrub/Other leads to increasing streamflow. Switching the Coniferous and Deciduous relative potential evapotranspiration coefficients generally reduces the streamflow sensitivity when the change is from Coniferous to other land covers, but because of the generally large area that is Range/Shrub/Other and Barren lands compared to Deciduous, the direction of the sensitivity is not changed.

SOME ECONOMIC CONSIDERATIONS

This section by John Keith, Economics Department, Utah State University, jkeith@econ.usu.edu

The value of additional water is dependent on time and place. The largest user of water in Utah is irrigated agriculture, diverting around 80% of total water diversions. In general, the value of additional water in irrigation is relatively low. Irrigation water in central Utah (Strawberry Water Users Association, see the Water Strategist, April, 2008) leases for from \$10 to \$20 per acre foot per year. The present value of these leases in perpetuity (purchase price) would probably be around \$200 to \$400 per acre foot at a 5% interest rate. There are relatively few water sales reported in Utah. Many of the exchanges in Utah are within an irrigation district or canal company. However, a comparison can be made among similar producers in other surrounding states. In Wyoming, irrigation water was leased from the Bureau of Reclamation for between \$3 and \$8 per acre foot, or about \$60 to \$160 in present value. It should be noted that the Bureau of Reclamation generally sells water at its cost, not at a market-determined price. The Central Arizona Project leases water for about \$100 per acre foot per year, and sells it at about \$650 per acre foot. In Wyoming, the Bureau of Reclamation leases water for from \$3 to \$8 per acre foot for irrigation, but the subsidies are relatively large. In Oregon, the Bureau of Reclamation leases water for from \$25 to \$75 per acre foot per year (See the Water Strategist, February, 2008 for details of all water sales in the western United States).

For Municipal and Industrial (M&I) water, the leasing and sales prices are much higher. Recently, the Washington County Water Conservancy District (Washington County, Utah) purchased shares (1 acre foot per share) from the St. George Washington Fields Canal Company for $3,000 per share, with the water destined for M&I use in St. George. The Northern Colorado Water Conservancy District has sold water to developers and municipalities for from $9,000 to $11,000 per "unit" for the past decade, with units yielding 60 to 80 percent of an acre foot. In Nevada, Truckee River water sells for around $25,000 per acre foot. In Arizona and California non-irrigation water sells for from $1,000 to $4,000 per acre foot. However, in Idaho, Idaho Falls City paid $300 per acre foot for irrigation water. (Water Strategist, February, 2008).

A second approach to examining the value of additional water to agriculture is to use "shadow values" which are derived from farm budgets or various kinds of mathematical programming models. These shadow values are developed based on the increasing profitability of irrigated production as water availability increases (or decreases). They represent a "residual" value of agricultural production with all costs deducted except water costs. While there are few recent studies of these shadow values, one model of the value of groundwater in the Beryl-Enterprise area suggests a shadow value of about $75 per acre foot per year, or about $1,500 (Keith, 2008). This value is based on the productivity of water in producing high-quality alfalfa. However, most studies (many completed in the 1980s) suggested a shadow value of $15 to $35 per acre foot per year, or around $300 to $700 present value per acre foot, particularly in locations with "typical" crop rotations (mid-quality alfalfa, grain, and corn). (See Young, 2005, for a review of these studies). Commodity prices are rising substantially at the moment, but so are the costs of inputs to production (other than water). What the resulting long-term shadow value will be is unknown, but the history of agriculture suggests that net returns to water will increase less quickly than inflation in the long run.

The existing literature and data from water markets indicate a wide range of economic value for additional water, so it is difficult to generalize about the value of the changes in water production indicated in the sensitivity analyses. Nevertheless, water for municipalities generally has a higher lease and sale price than irrigation water, which suggests that increases in water production from watersheds serving urban areas are likely to have relatively high returns, while water increases used for irrigation will have relatively low returns.

DISCUSSION AND CONCLUSIONS

Mann Kendall runoff ratio trend analysis results revealed that there is a significant decreasing trend for 14 of the study watersheds, with this trend being highly significant (statistically) in Weber River near Plain City, Virgin River at Virgin, Rock Creek near Mountain Home, Duchesne River near Tabiona and Sevier River at Hatch watersheds. Analysis of the annual, as well as seasonal, temperature records revealed that there are increasing temperature trends for most of the watersheds studied (Figure 7.1 through Figure 7.39). No significant trends in precipitation were seen in any study watersheds. A decreasing trend in runoff ratio (Q/AP) means that less of the precipitation leaves the watershed in the form of streamflow. In the watersheds where there are significant decreases in Q/AP, these decreases may be directly due to diversions, storage, and water use or due to increases in evapotranspiration due to land use changes or temperature changes. Five of the 39 watersheds examined were HCDN watersheds deemed to be relatively free from direct effects of diversions and use. One of these watersheds, the Sevier River at Hatch (#2201), had a decreasing streamflow and runoff ratio trend (Figure 3.38). The cause for this is not known, although one reviewer noted that the Sevier River at Hatch has at least four major diversions in it, calling into question its inclusion in the USGS HCDN network of relatively unimpacted streams.

We looked for patterns relating land cover change to trends in runoff ratio. Watersheds with decreasing runoff ratio trends occurred in three of the four predominant land cover change classes that we identified, as well as in watersheds where land cover was not changing. However, there are a comparable number of watersheds in each predominant land cover change class that do not have significant runoff ratio trends as do have significant trends. We are, consequently, unable to find consistent relationships between land cover change and runoff ratio trends.

Consequently, the specific causes for the decreasing trends in runoff ratio for 14 of the study watersheds are not known. All potentially include areas with significant diversions and water use that has not been quantified in this study. The reductions are likely due to a combination of these diversions as well as increases in evapotranspiration related to temperature and land cover changes.

In the analysis of land cover data, we found that unequivocal interpretation of land cover changes was confounded by differences in methodology and technology used to determine land cover over time. The NLCD 1992 and NLCD 2001 are not designed for direct comparison (Homer et al., 2007). This is clearly seen in the classification scheme and the way each map was recoded (for example forest and range types). Detecting the change in land cover and land use through the state remains a challenge because of this inconsistency in methods used to produce nationally available land cover datasets. We have been told that the USGS is testing a new tool that provides the connection between NLCD 1992, NLCD 2001, and the new product of NLCD 2006 that may resolve some of these difficulties.

Given that we were unable to derive relationships from the data as to how land cover and land use affect water production, and so as to provide some information helpful for land management policy making and economic analyses, we developed the water balance approach that quantifies sensitivity of runoff production to changes in land cover based on differences in evapotranspiration from different land cover types. The coefficients that quantify the potential evapotranspiration from each land cover type in this analysis are based on our judgment and information from the literature. In coming up with these coefficients, we also endeavored to reconcile them with precipitation, streamflow, and runoff ratio data for the Utah study watersheds. The water balance approach was used to analyze the sensitivity of water production to land cover changes for five land cover types for the Utah study watersheds.

Physical understanding of the interactions between hydrology, climate, and land cover changes is important for understanding and predicting the potential hydrological consequences of existing land use practices. The results of this work developed an integrative-quantitative procedure for understanding relations among watershed management practices, and water balance quantities. The theoretical approach taken in this study is simple and general and could be applied to a wide range of watersheds throughout the state. However, it depends directly upon the relative evapotranspiration coefficients. It is, therefore, important to consider future work to better quantify the relative impact of land cover on evapotranspiration and streamflow production. Both computer modeling and observations may be required to advance knowledge in this area.

It is important to note that using the Budyko relation as a single valued function ignores the scatter that typically occurs around a Budyko curve when water balance partition observations are plotted. This scatter has many causes such as seasonality and variability in hydrologic processes not captured by this aggregate model. By using a range of values for the parameter ν, some sensitivity to this uncertainty was assessed. Also, the approach presented above uses the Budyko relation in a relative sense so some of these uncertainty effects balance off against each other. This was outlined through steps II and V in which we estimated in step II the watershed average land cover adjusted reference evapotranspiration, R, while in step V we solve the Budyko relation to find the updated evapotranspiration given the new watershed average land cover adjusted reference evapotranspiration, R'.

We caution that, in the use of these sensitivity results, the sensitivities depend directly upon the coefficients that quantify the potential evapotranspiration from each land cover type. This represents a fairly gross simplification. In semi-arid settings the vegetation water use is often limited by water availability, rather than potential evapotranspiration, and differences in water yield may relate more to factors such as the timing and rate of water inputs (precipitation intensity and snowmelt). Vegetation also depends strongly on topographic setting, due to factors such as elevation, aspect, and solar radiation exposure. Changes in the proportioning of land cover in a watershed, therefore, should consider the control that topographic setting has on land cover.

APPENDIX 1

Snow Water Equivalent averaging procedure

This appendix describes the procedure used to adjust snow water equivalent averages to remove bias due to record length differences at individual sites. This procedure is from Mohammed (2006) and was developed to have an average over the full length of record that is comparable to the average from all sites. It is based on the idea that the average—when a site does not have data (i.e. before it was established—should be adjusted by the ratio of the average of all sites to the average with that site left out, over the period where common data is available. The procedure is illustrated in Figure 9 for four stations ranked by their period of record. Stations S1 and S2 have periods of record from year n1=n2 to present, p. Station S3 has period of record from n3>n2 to present, p, and station S4 has period of record from n4>n3 to present, p. Stations S1 and S2 have full records, but S3 has a shorter record and S4 the shortest, in this illustrative example. For each year the unadjusted average is simply the mean across all stations with data. Thus the unadjusted average in year i is represented by:

U(i)=Ave(S(1:4,i)) for i ranging from n4:p
U(i)=Ave(S(1:3,i)) for i ranging from n3:(n4-1)
U(i)=Ave(S(1:2,i)) for i ranging from n2:(n3-1) (recalling that n1=n2)

where Ave(.) denotes averaging and S(s,y) denotes the specific end of month snow water equivalent values for a station (or range or stations), s, and year, y and the unadjusted average in year i is denoted by U(i).

The adjusted average for the year i will be denoted by X(i). For the years n4 to p, no adjustments are needed so we have
X(i)=U(i)   i in n4:p

For the years n3 to n4-1, i.e., the years when S4 does not have a record the adjusted average is calculated as:
X(i)=Ave(S(1:3,i))*Ave(S(1:4,n4:p))/Ave(S(1:3,n4:p))
    =U(i)*Ave(X(n4:p))/Ave(S(1:3,n4:p))   i in n3:(n4-1)

Similarly, the adjusted average for the year i in the range n2 to n3-1, i.e. the years when S3 and S4 do not have records, is calculated as:
X(i)=U(i)*Ave(X(n3:p))/Ave(S(1:2,n3:p))   i in n2:(n3-1)

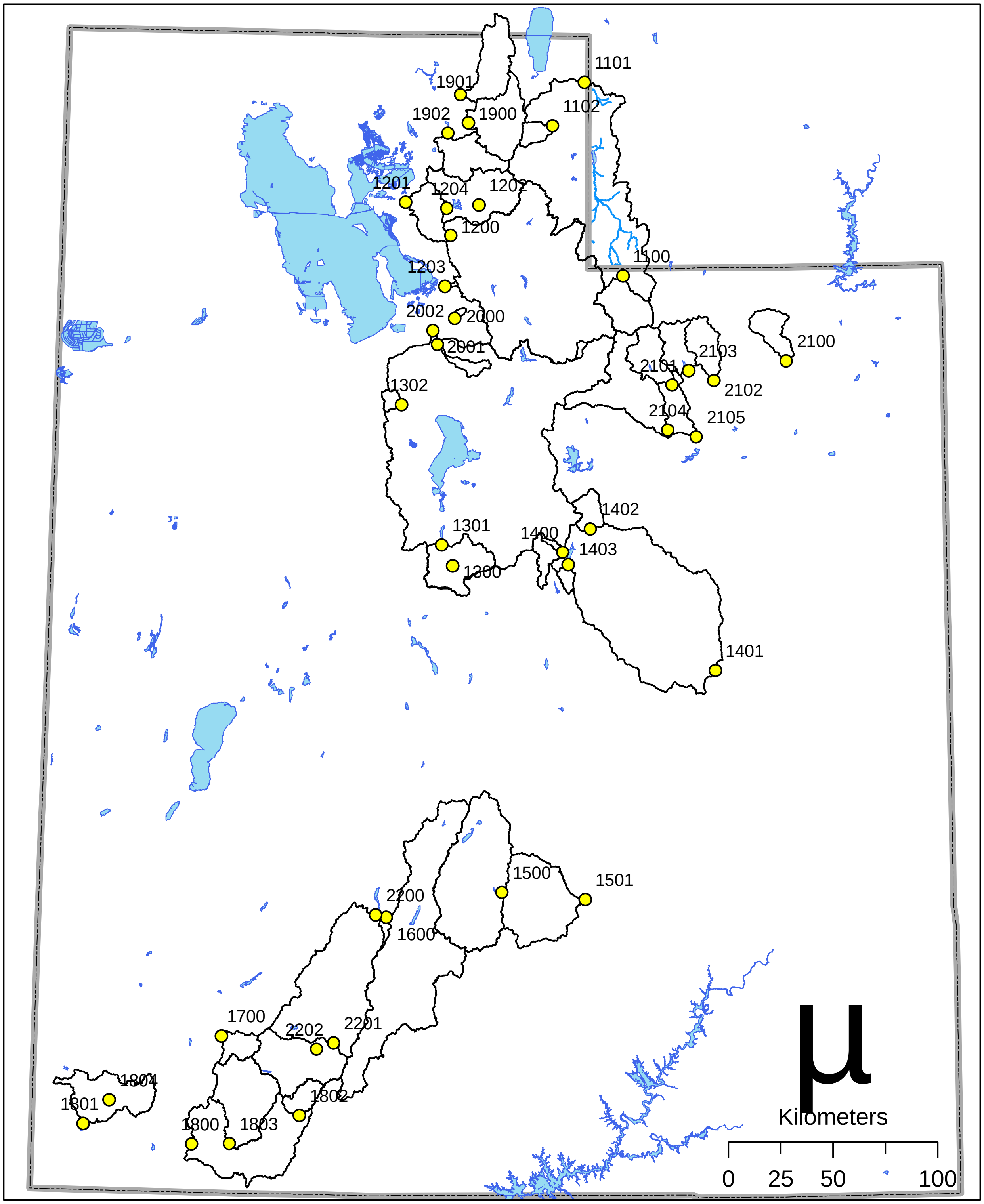

Figure 1. *Study watersheds.*

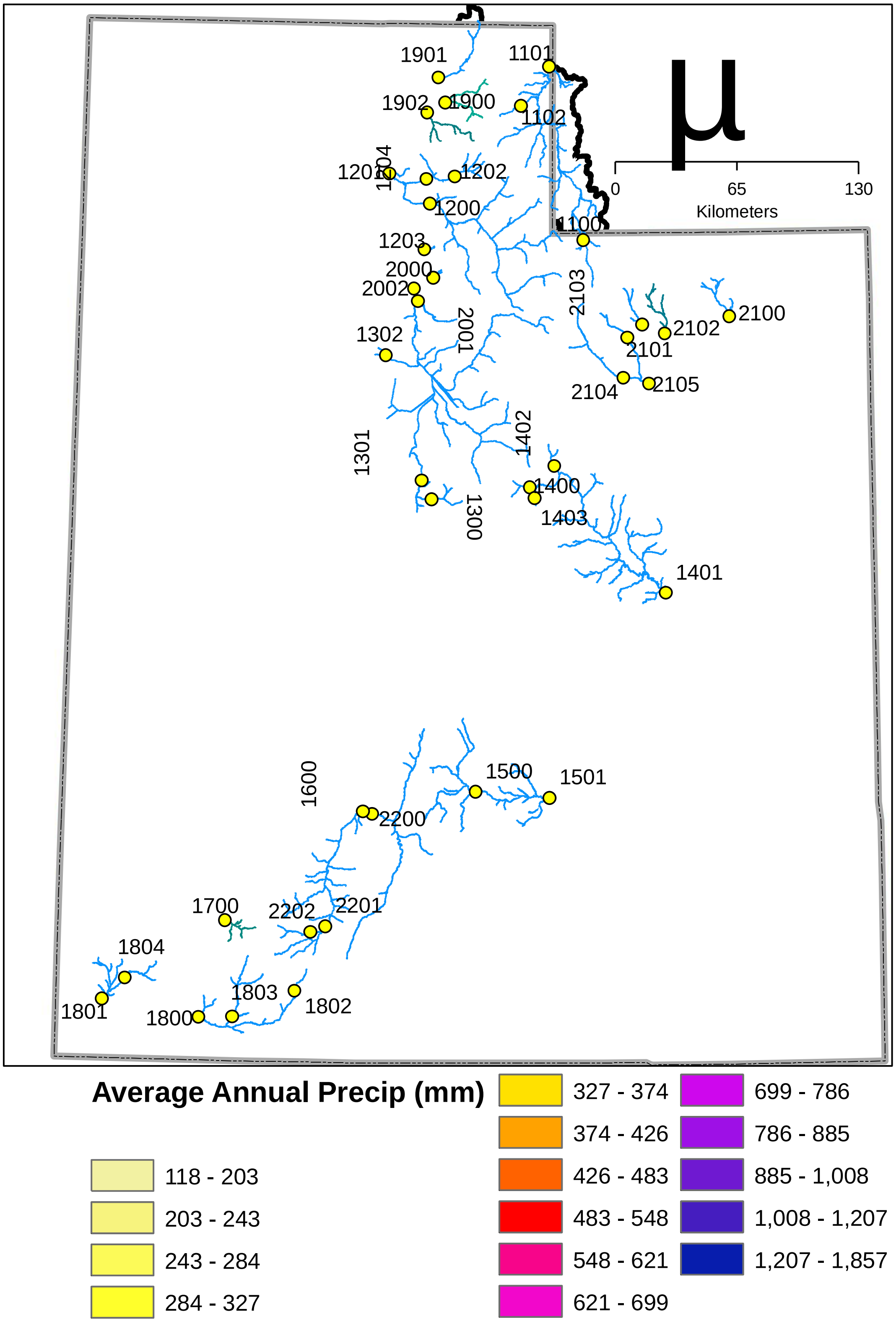

Figure 2. *Utah 30 year (1971-2000) average annual precipitation from PRISM.*

Watershd_ID = 1100

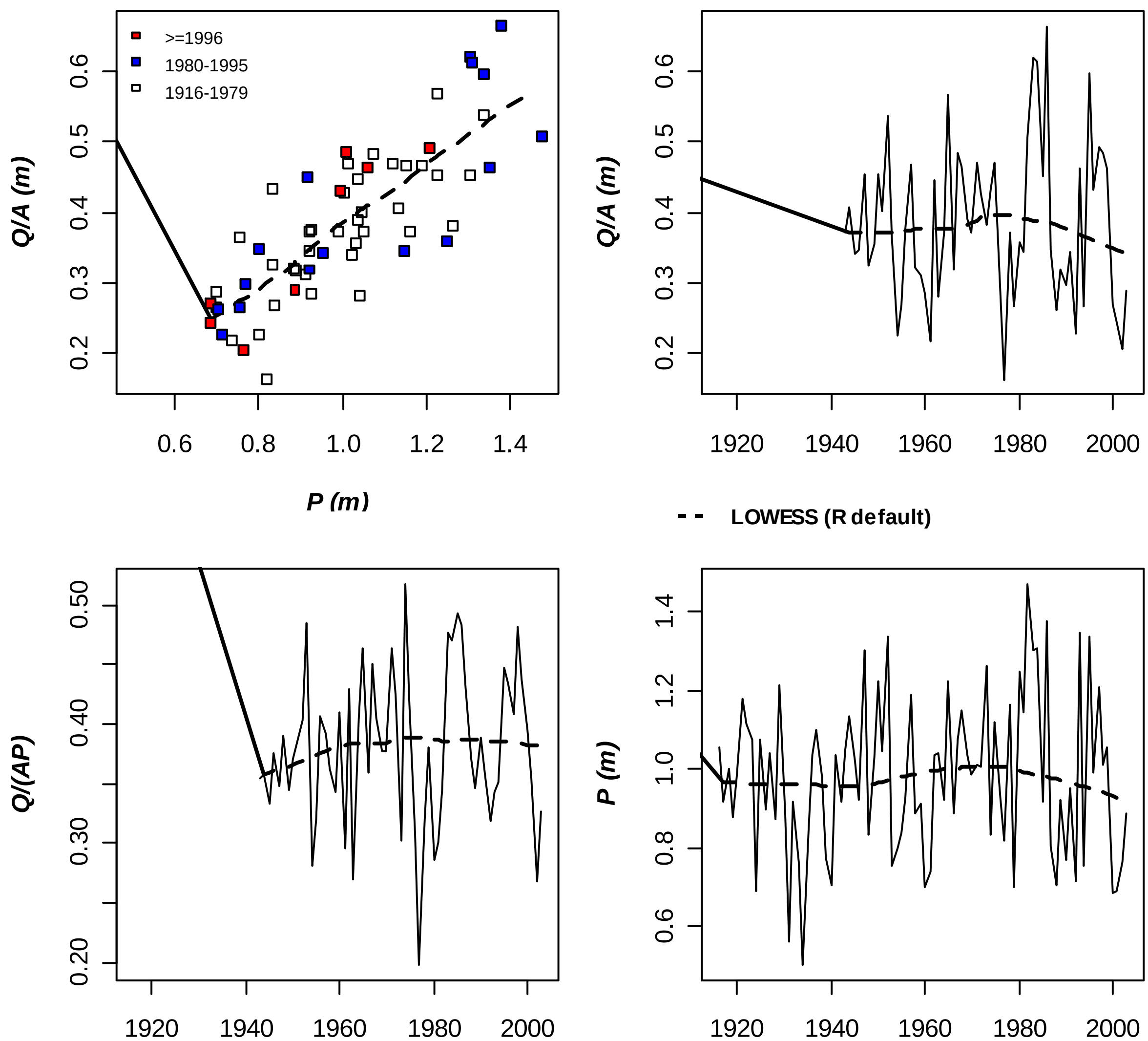

Figure 3.1. *Precipitation and streamflow trend analysis for the Bear River near Utah-Wyoming state line watershed (watershed_ID = 1100).*

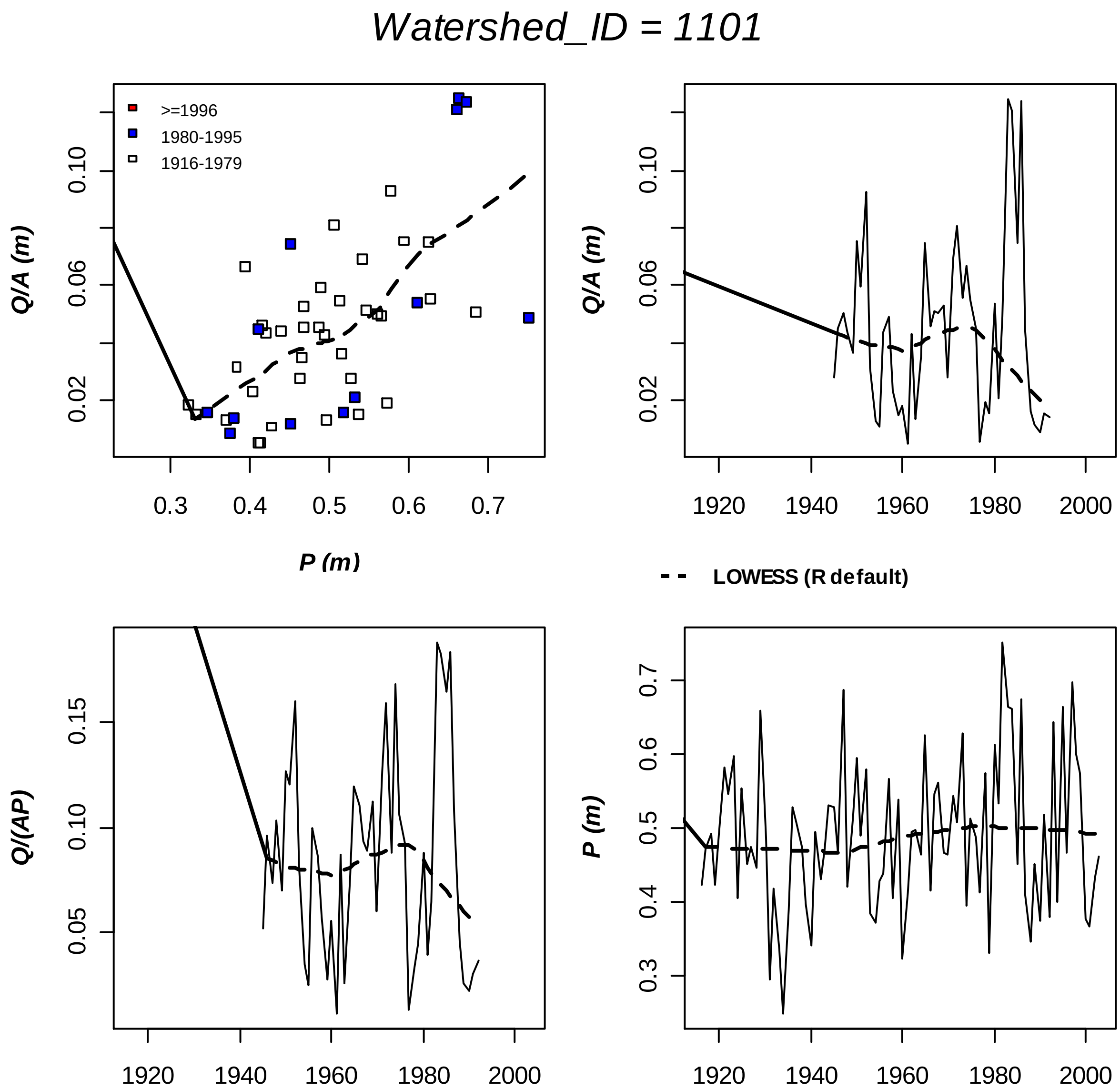

Figure 3.2. Precipitation and streamflow trend analysis for the Bear River near Randolph watershed (watershed_ID = 1101).

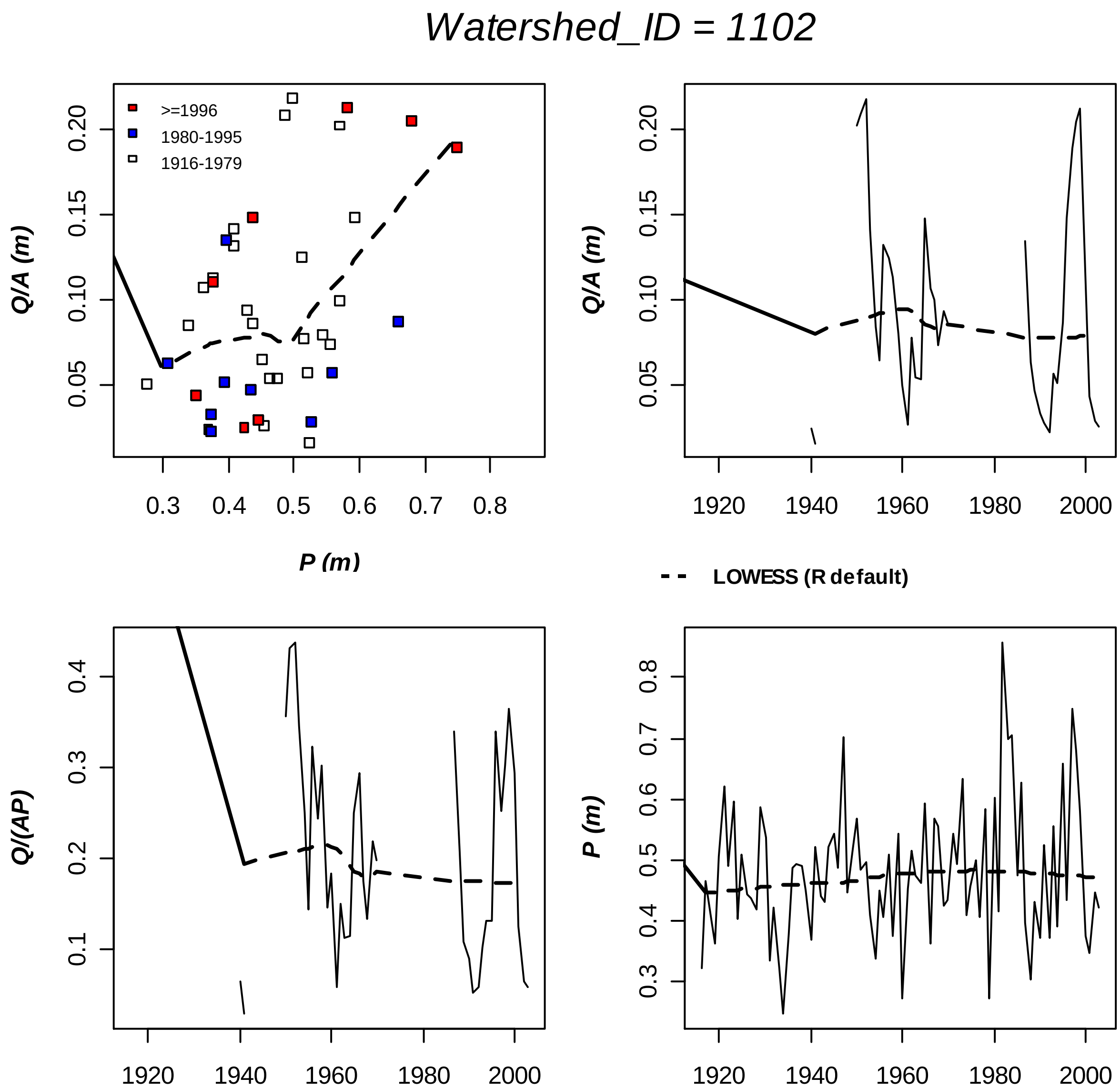

Figure 3.3. *Precipitation and streamflow trend analysis for the Big Creek near Randolph watershed (watershed_ID = 1102).*

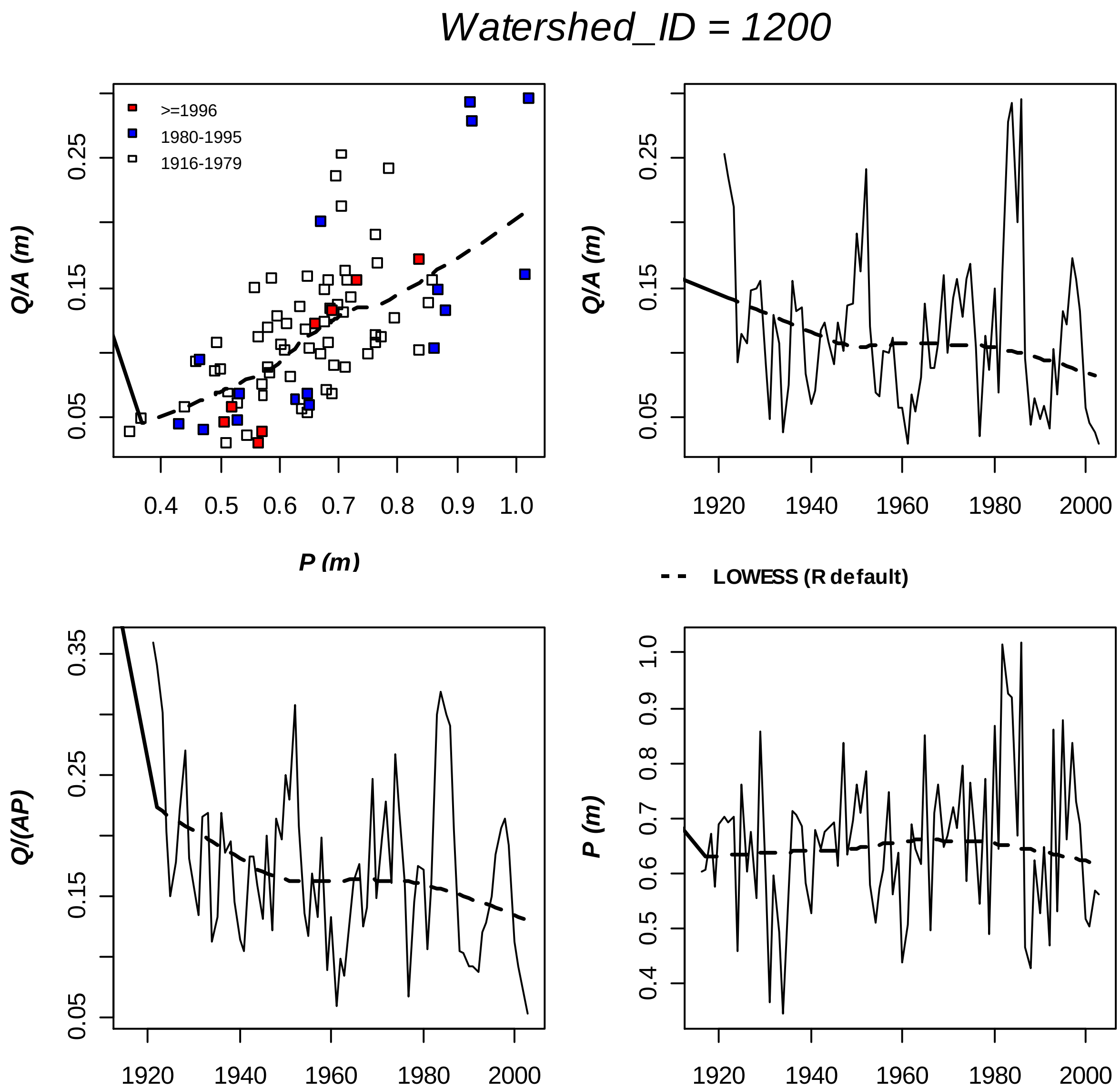

Figure 3.4. *Precipitation and streamflow trend analysis for the Weber River at Gateway watershed (watershed_ID = 1200).*

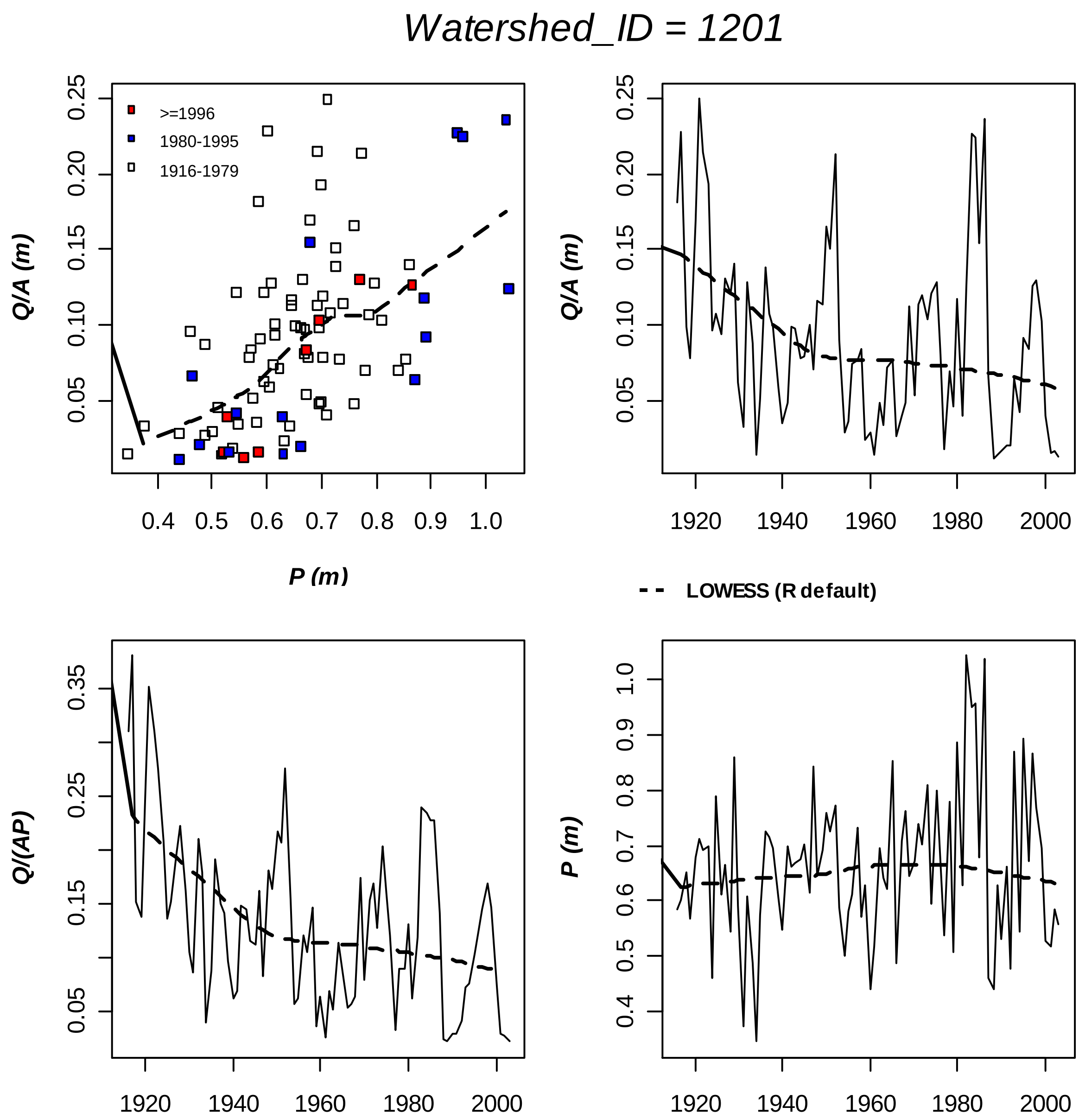

Figure 3.5. *Precipitation and streamflow trend analysis for the Weber River near Plain city watershed (watershed_ID = 1201).*

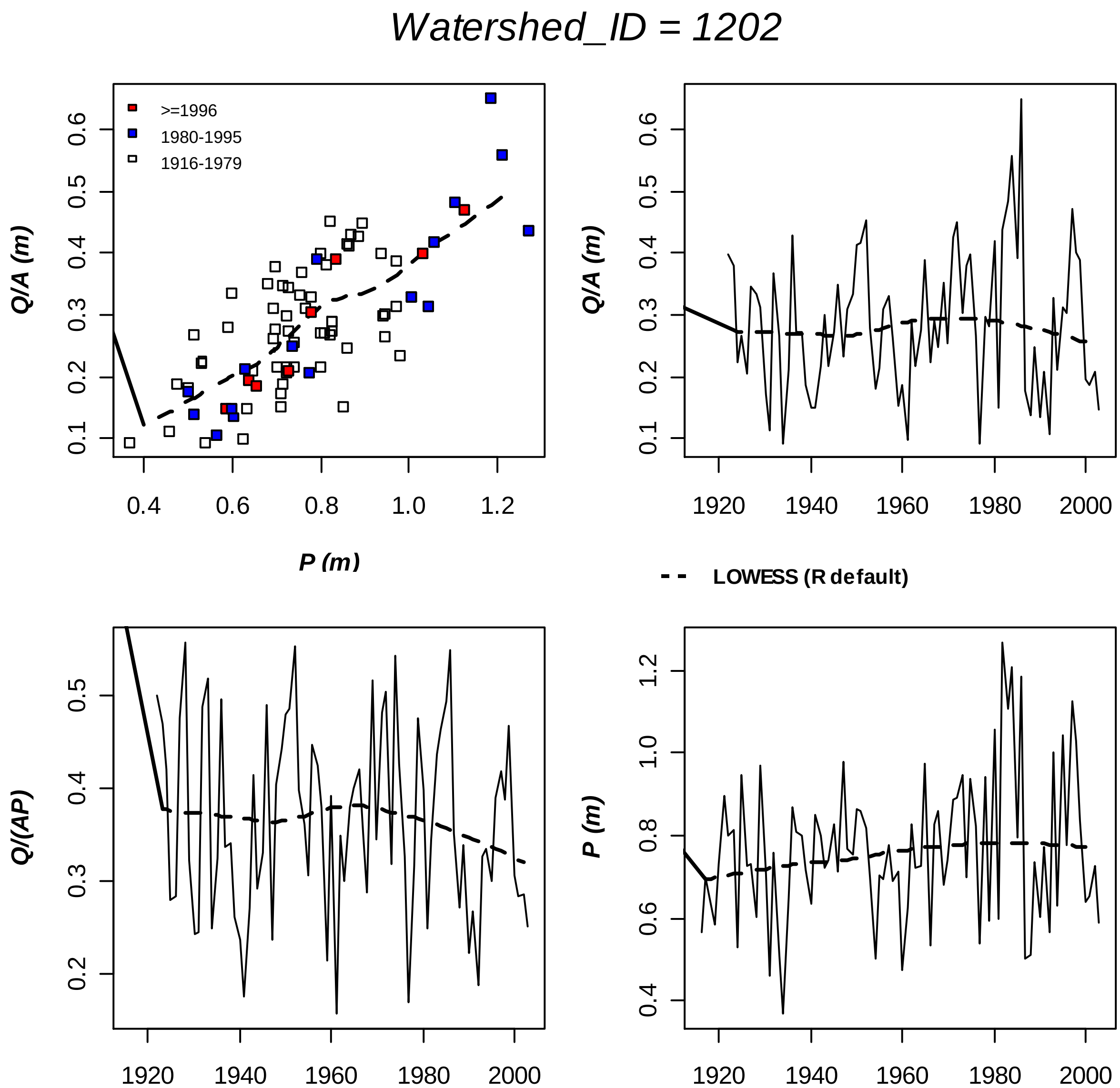

Figure 3.6. *Precipitation and streamflow trend analysis for the South Fork Ogden River near Huntsville watershed (watershed_ID = 1202).*

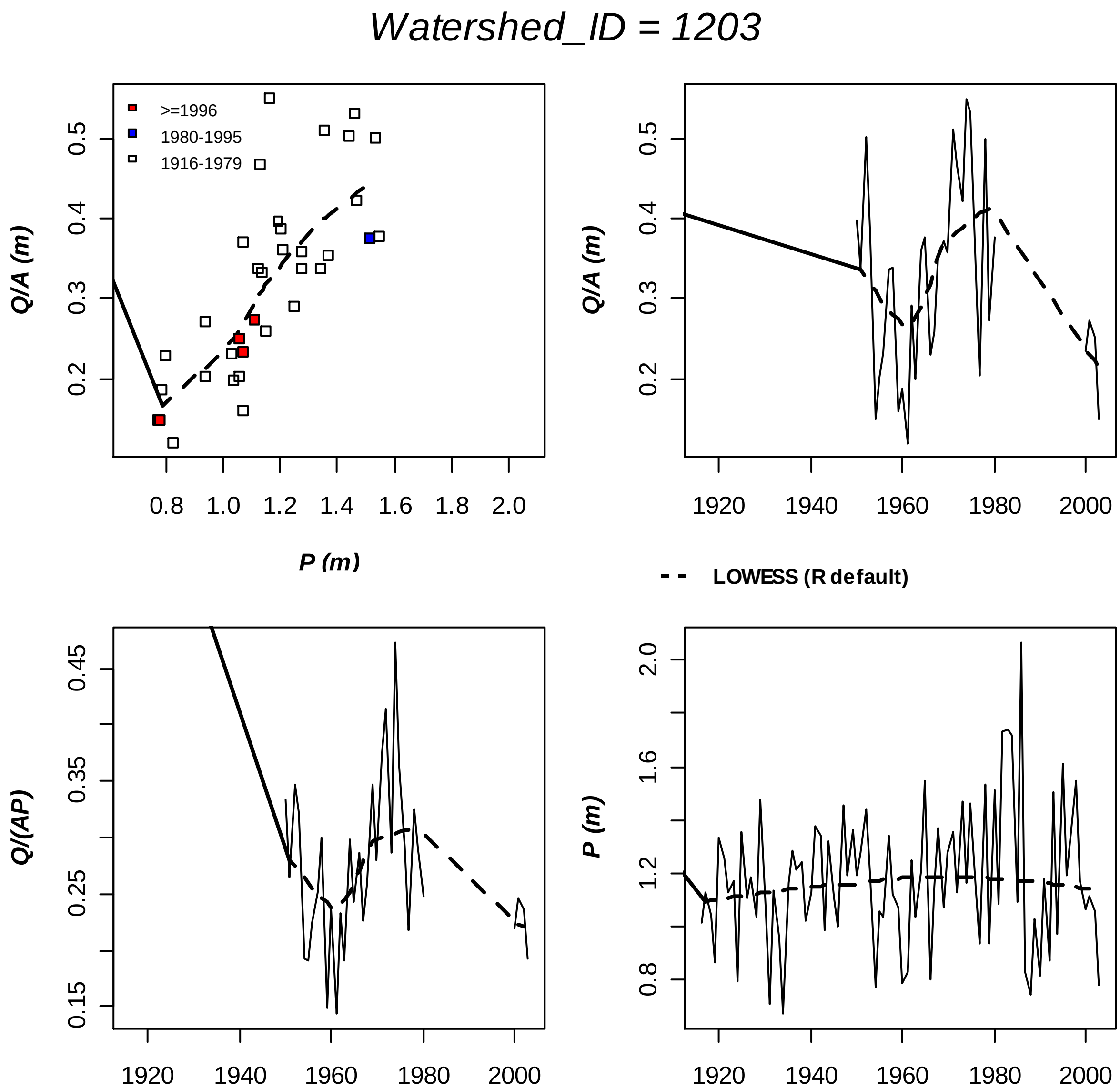

Figure 3.7. *Precipitation and streamflow trend analysis for the Centerville Creek near Centerville watershed (watershed_ID = 1203).*

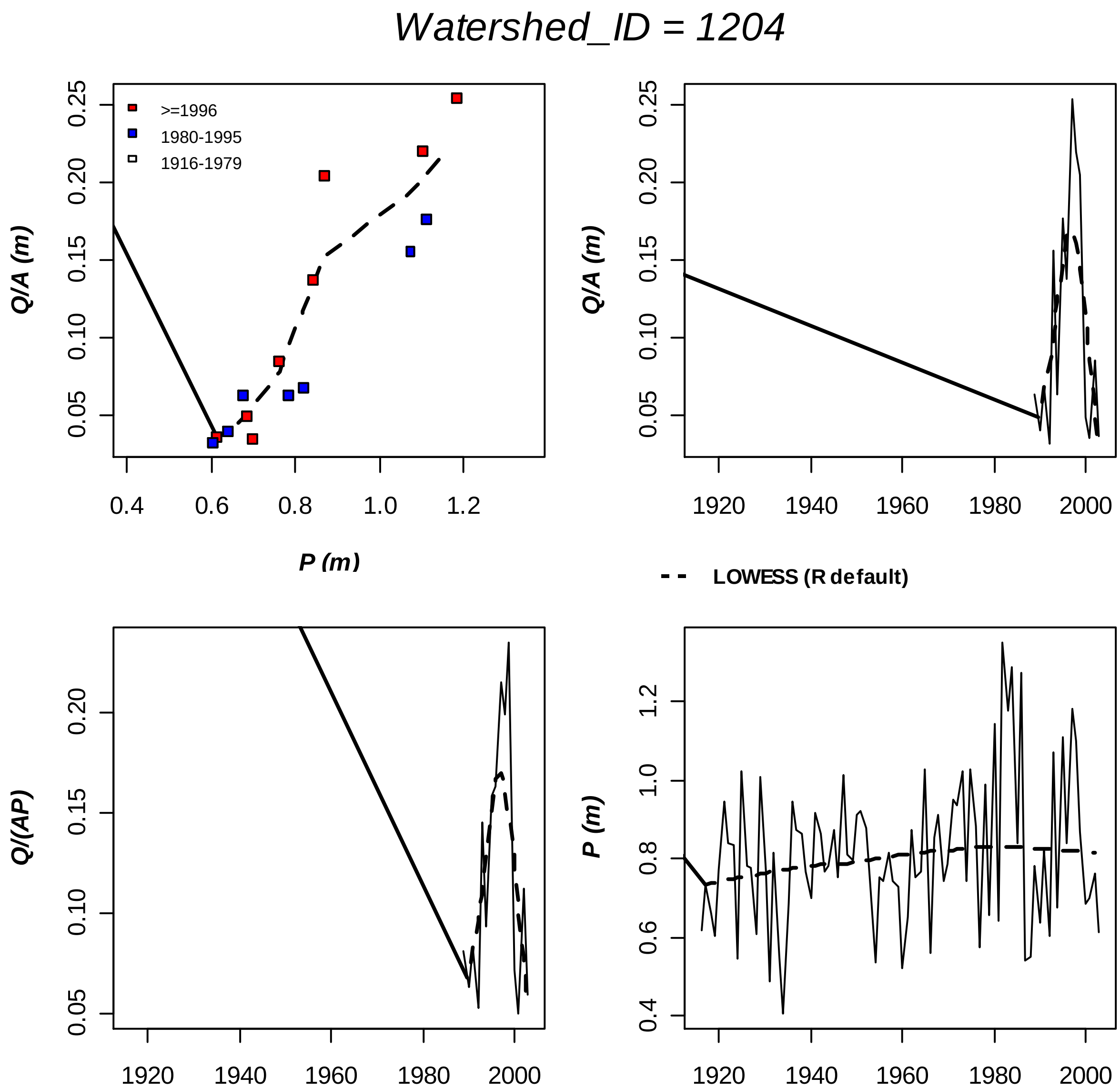

Figure 3.8. *Precipitation and streamflow trend analysis for the Ogden River below Pineview near Huntsville watershed (watershed_ID = 1204).*

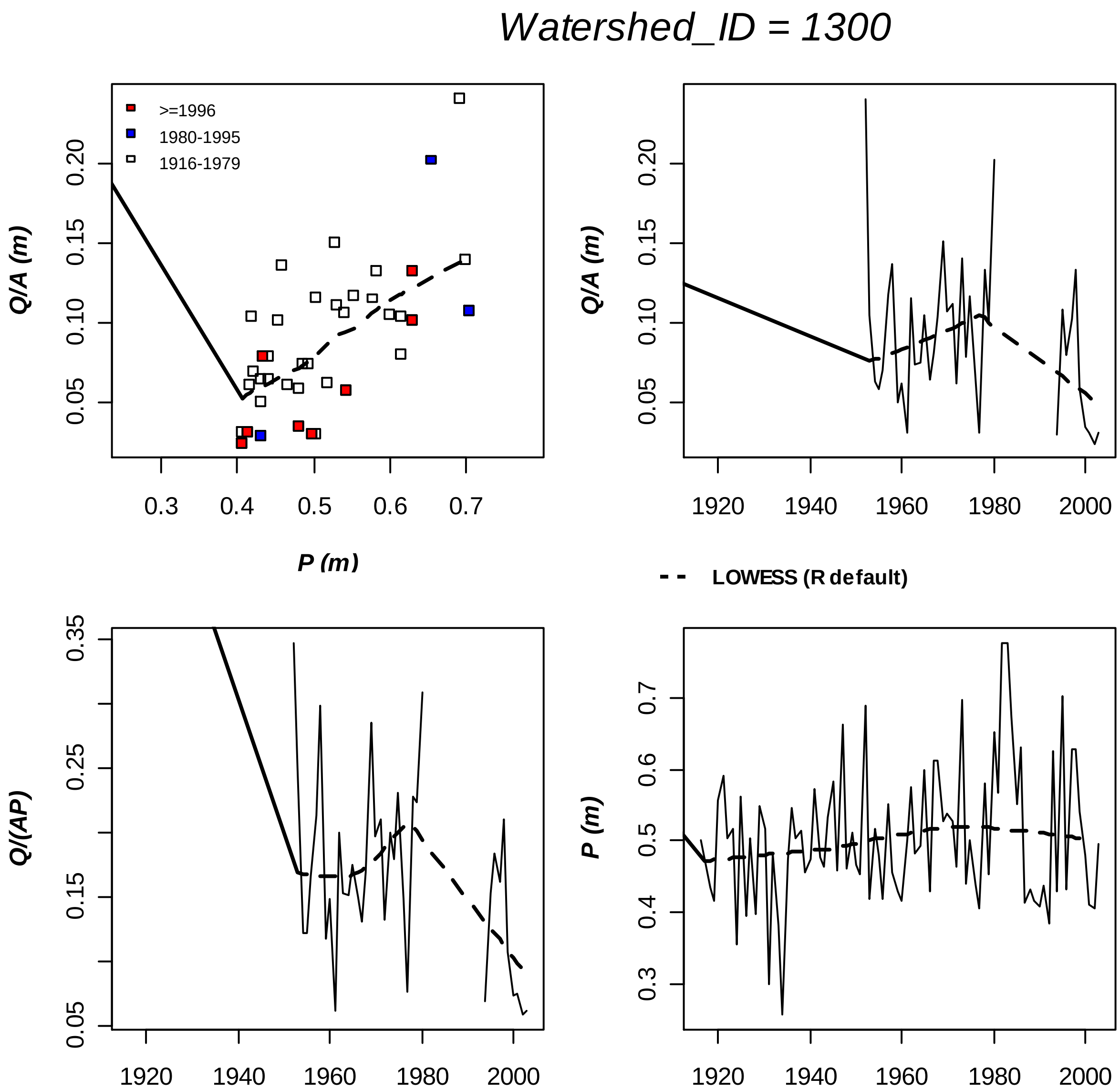

Figure 3.9. *Precipitation and streamflow trend analysis for the Salt Creek at Nephi watershed (watershed_ID = 1300).*

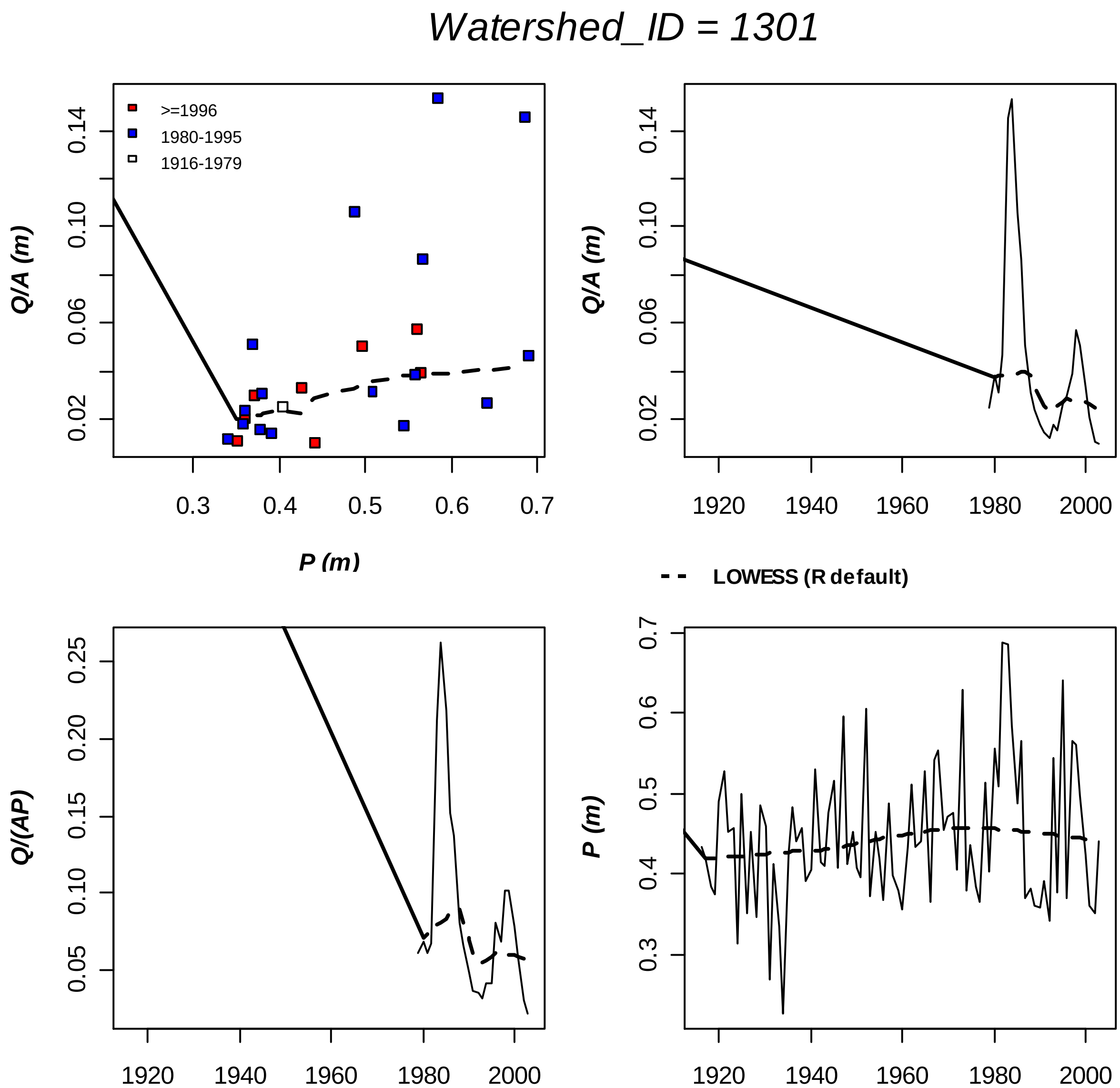

Figure 3.10. *Precipitation and streamflow trend analysis for the Currant Creek near Mona watershed (watershed_ID = 1301).*

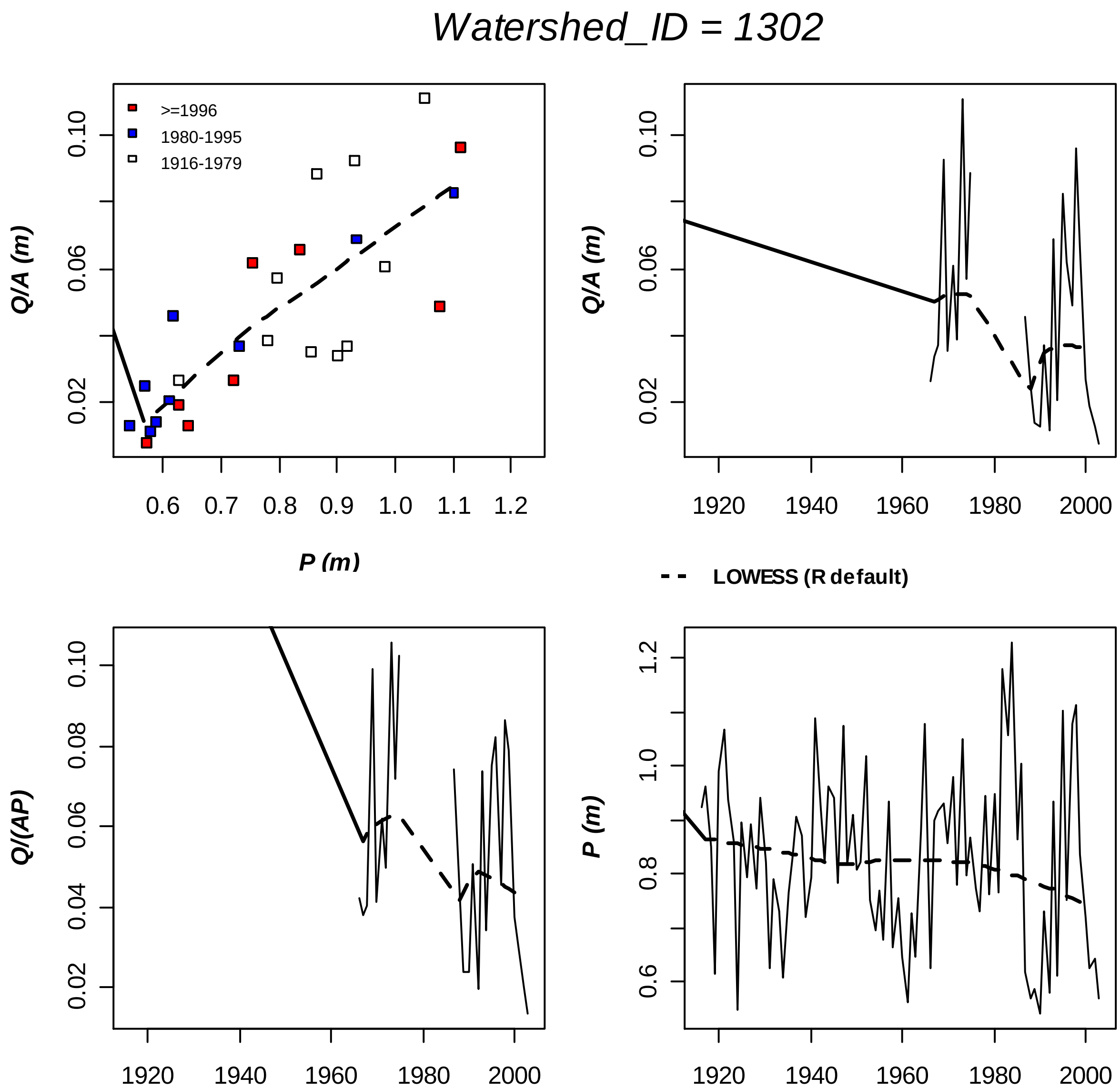

Figure 3.11. *Precipitation and streamflow trend analysis for the West Canyon Creek near Cedar Fort watershed (watershed_ID = 1302).*

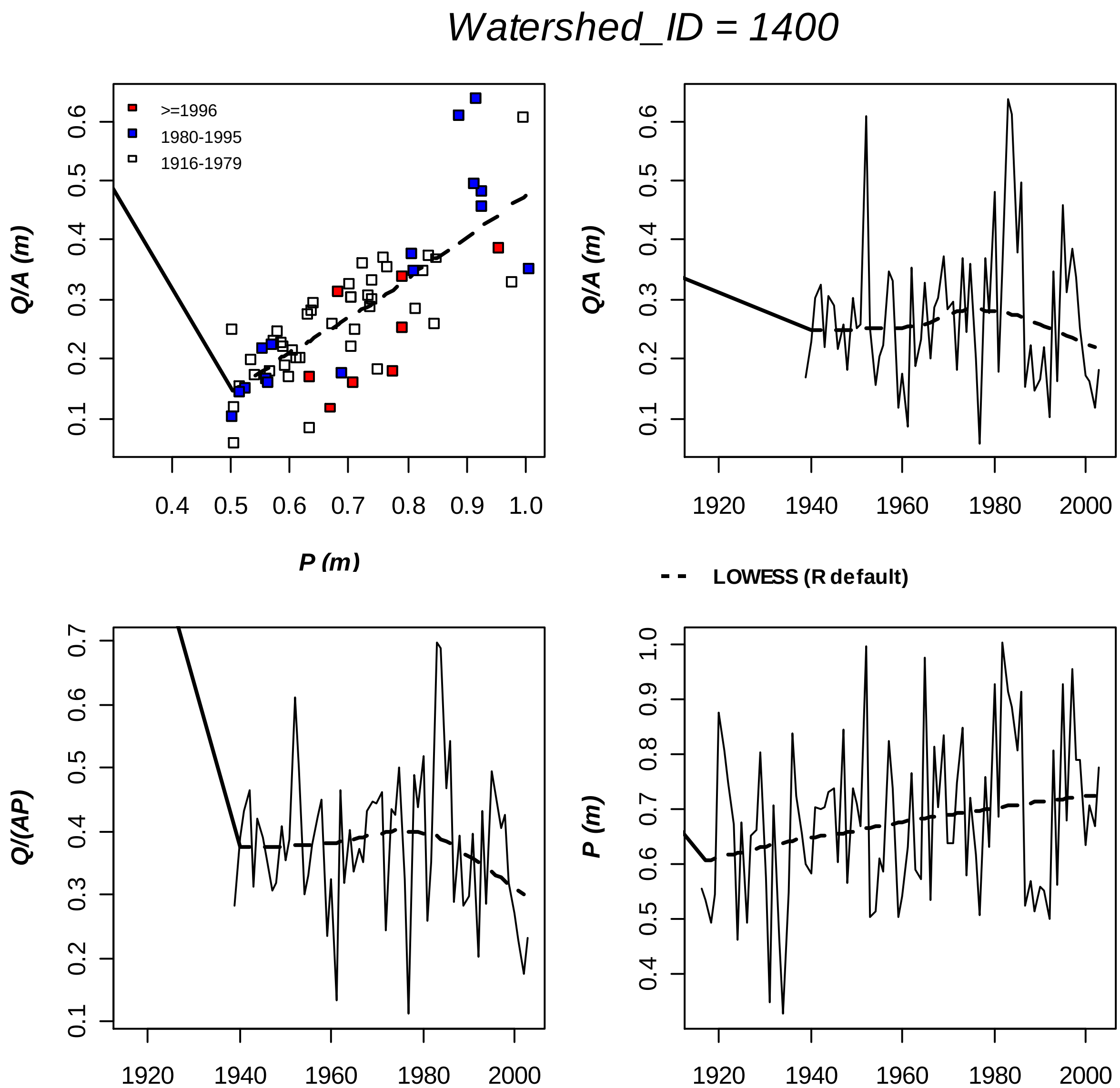

Figure 3.12. *Precipitation and streamflow trend analysis for the Fish Creek near Scofield watershed (watershed_ID = 1400).*

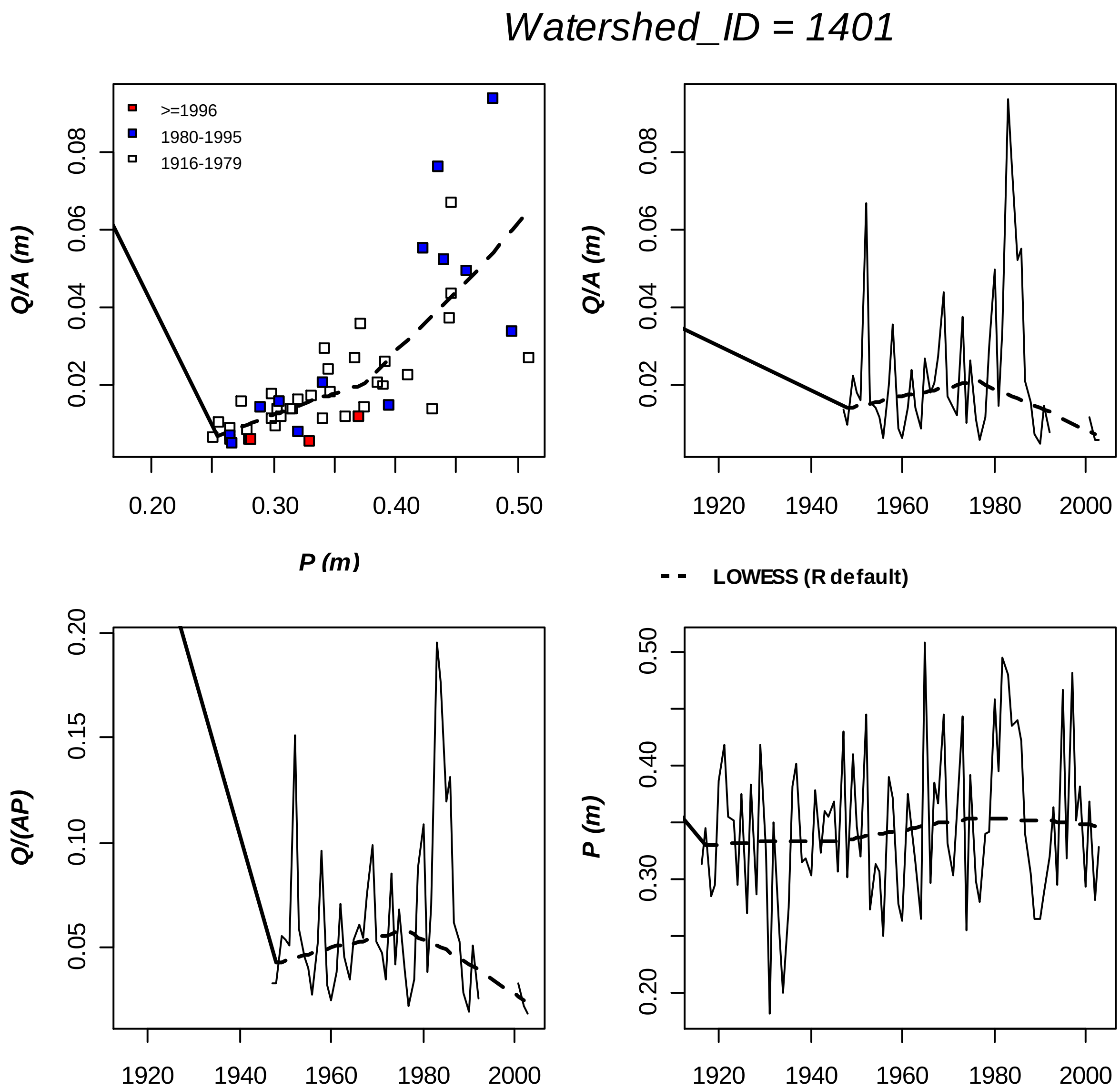

Figure 3.13. *Precipitation and streamflow trend analysis for the Price River at Woodside watershed (watershed_ID = 1401).*

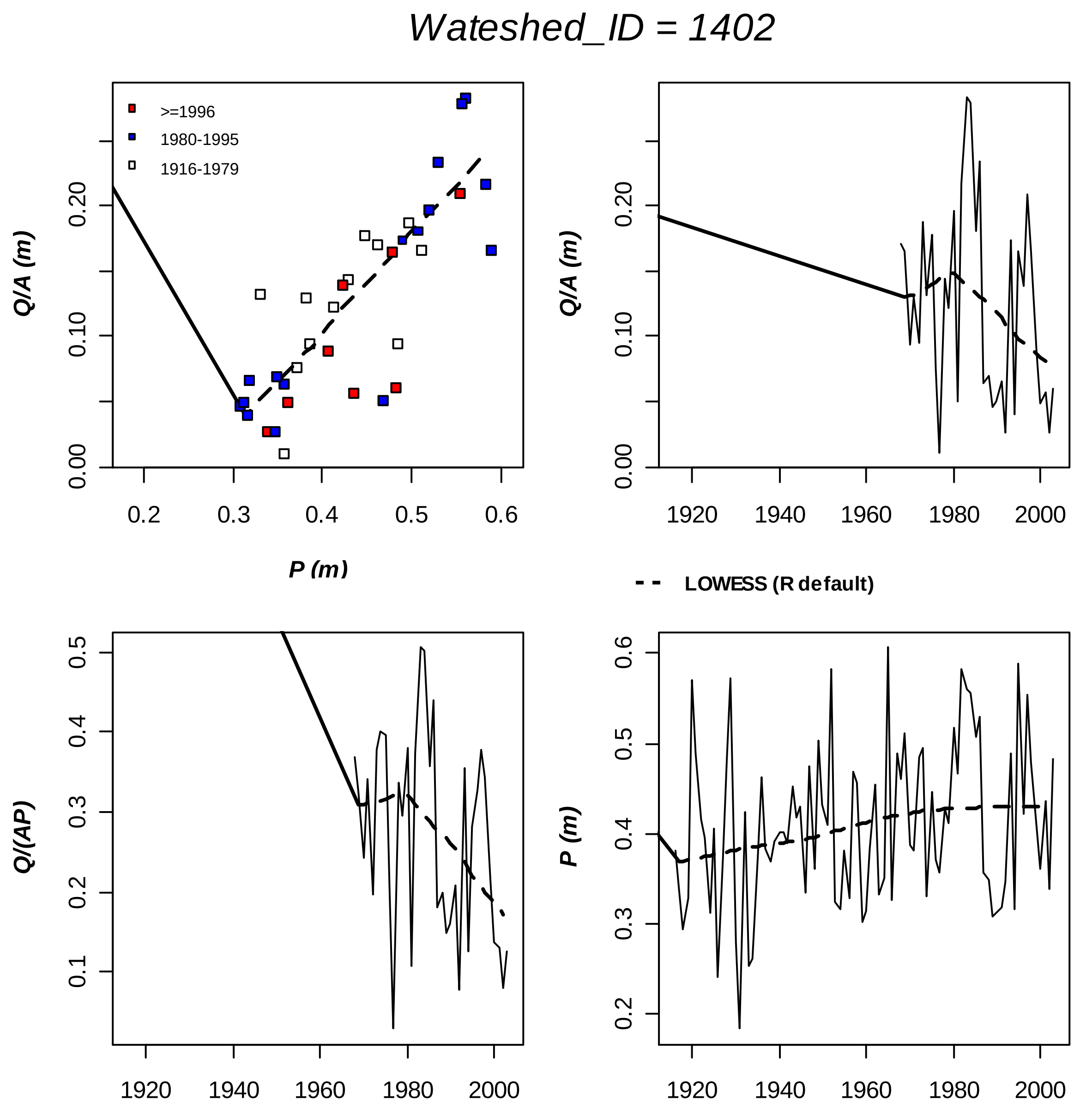

Figure 3.14. *Precipitation and streamflow trend analysis for the White River below Tabbyune Creek near Soldier Summit watershed (watershed_ID = 1402).*

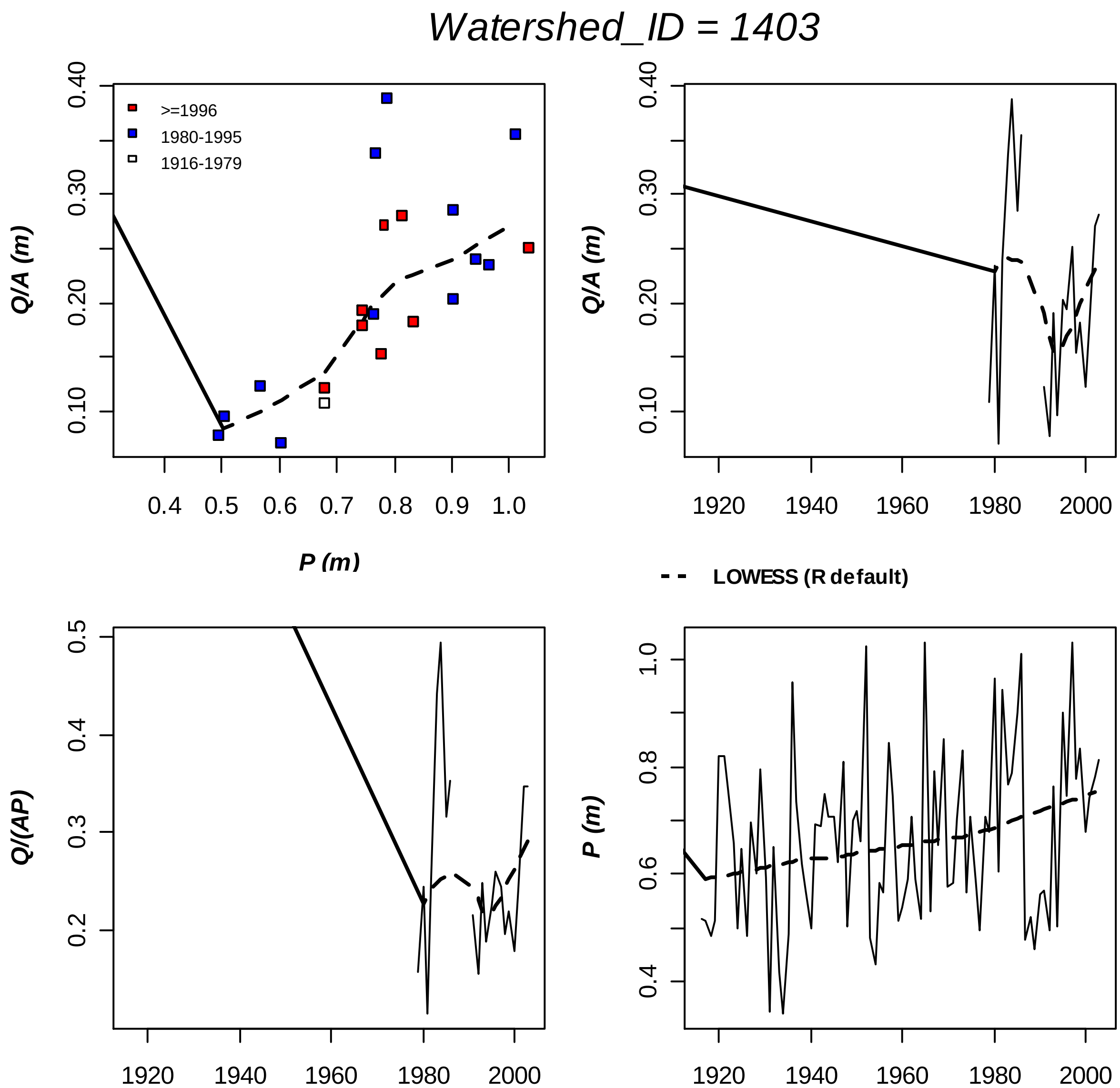

Figure 3.15. *Precipitation and streamflow trend analysis for the Mud Creek below Winter Quarters Canyon at Scofield watershed (watershed_ID = 1403).*

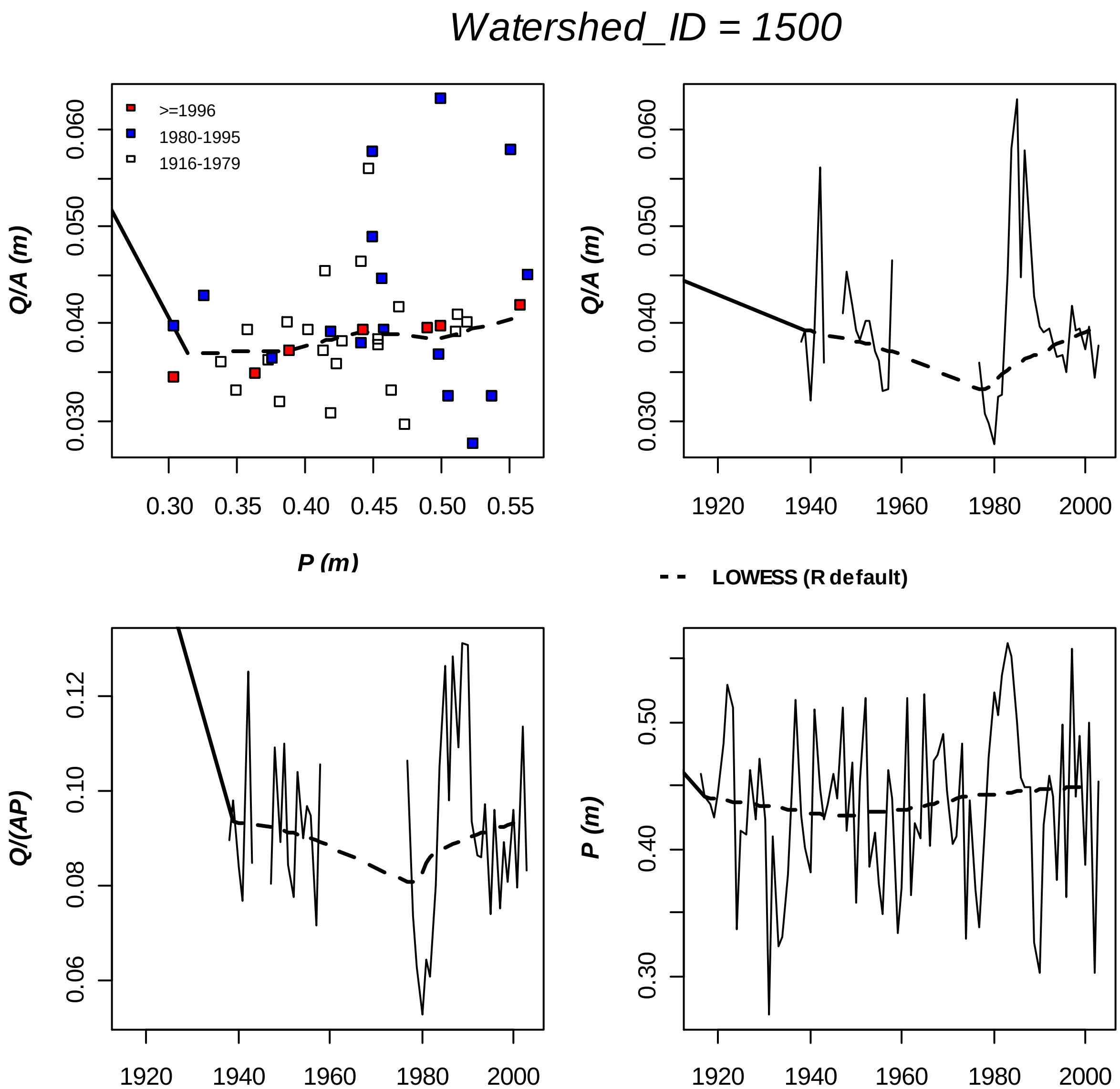

Figure 3.16. *Precipitation and streamflow trend analysis for the Fremont River near Bicknell watershed (watershed_ID = 1500).*

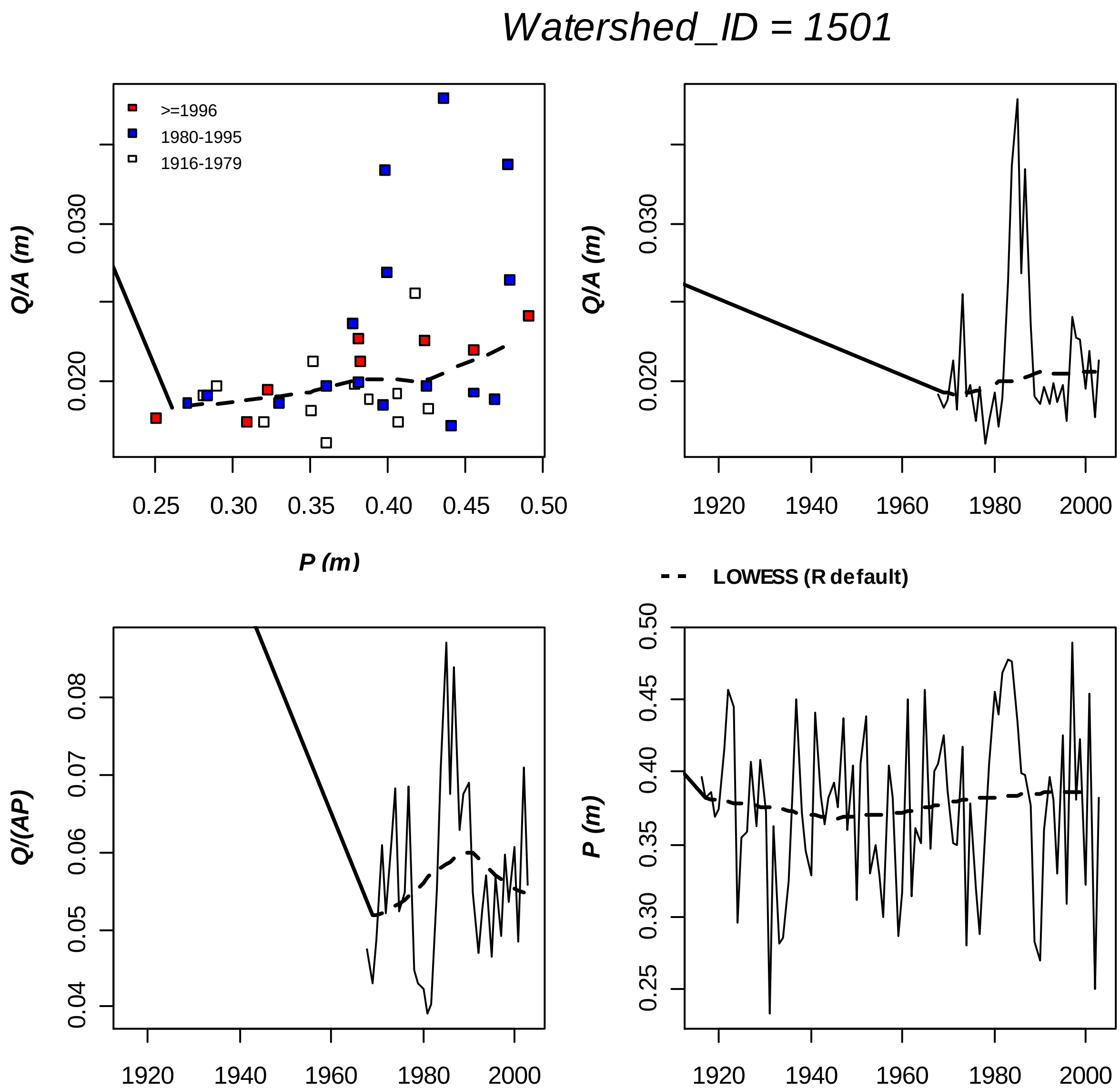

Figure 3.17. *Precipitation and streamflow trend analysis for the Fremont River near Caineville watershed (watershed_ID = 1501).*

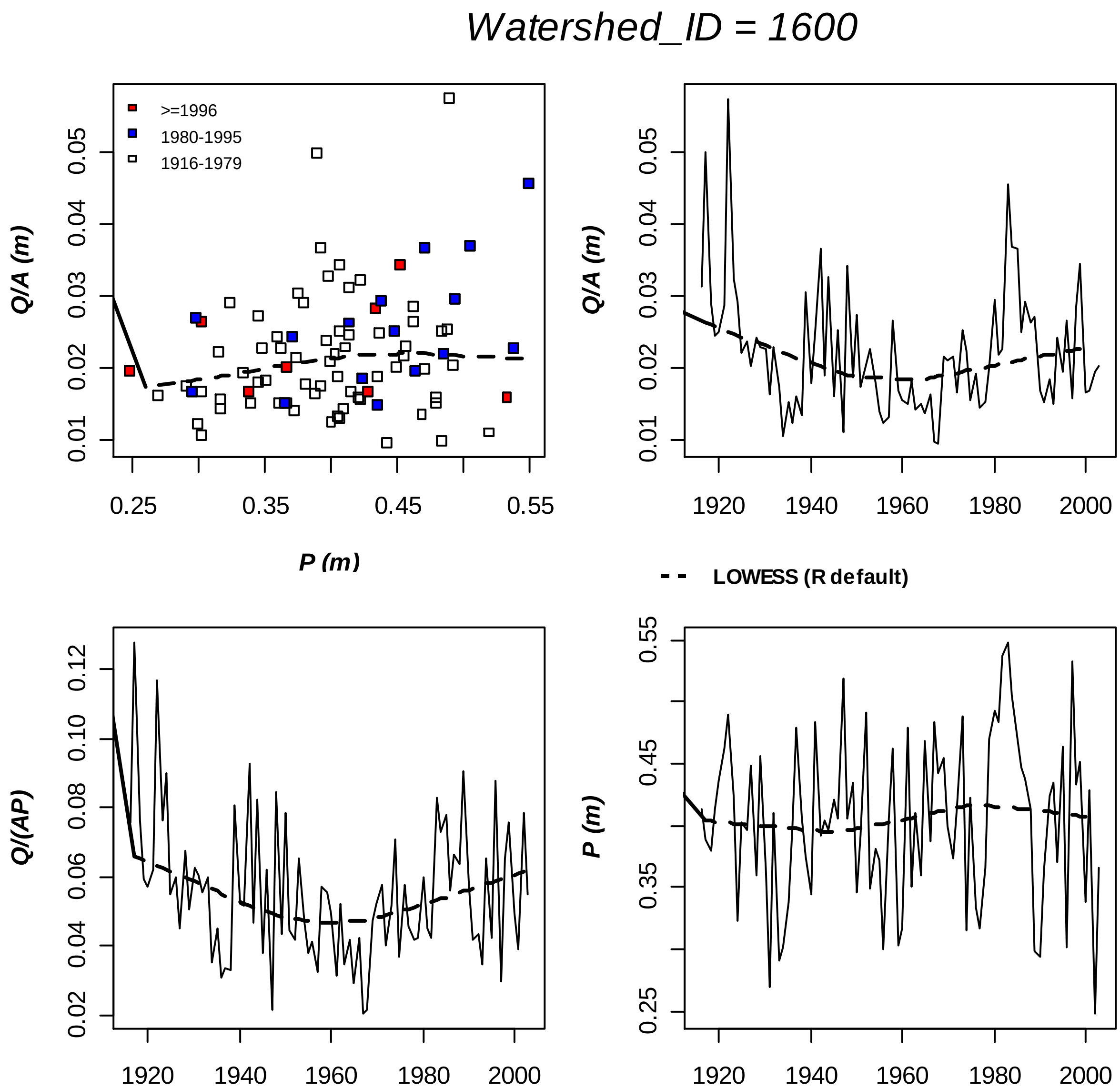

Figure 3.18. *Precipitation and streamflow trend analysis for the East Fork Sevier River near Kingston watershed (watershed_ID = 1600).*

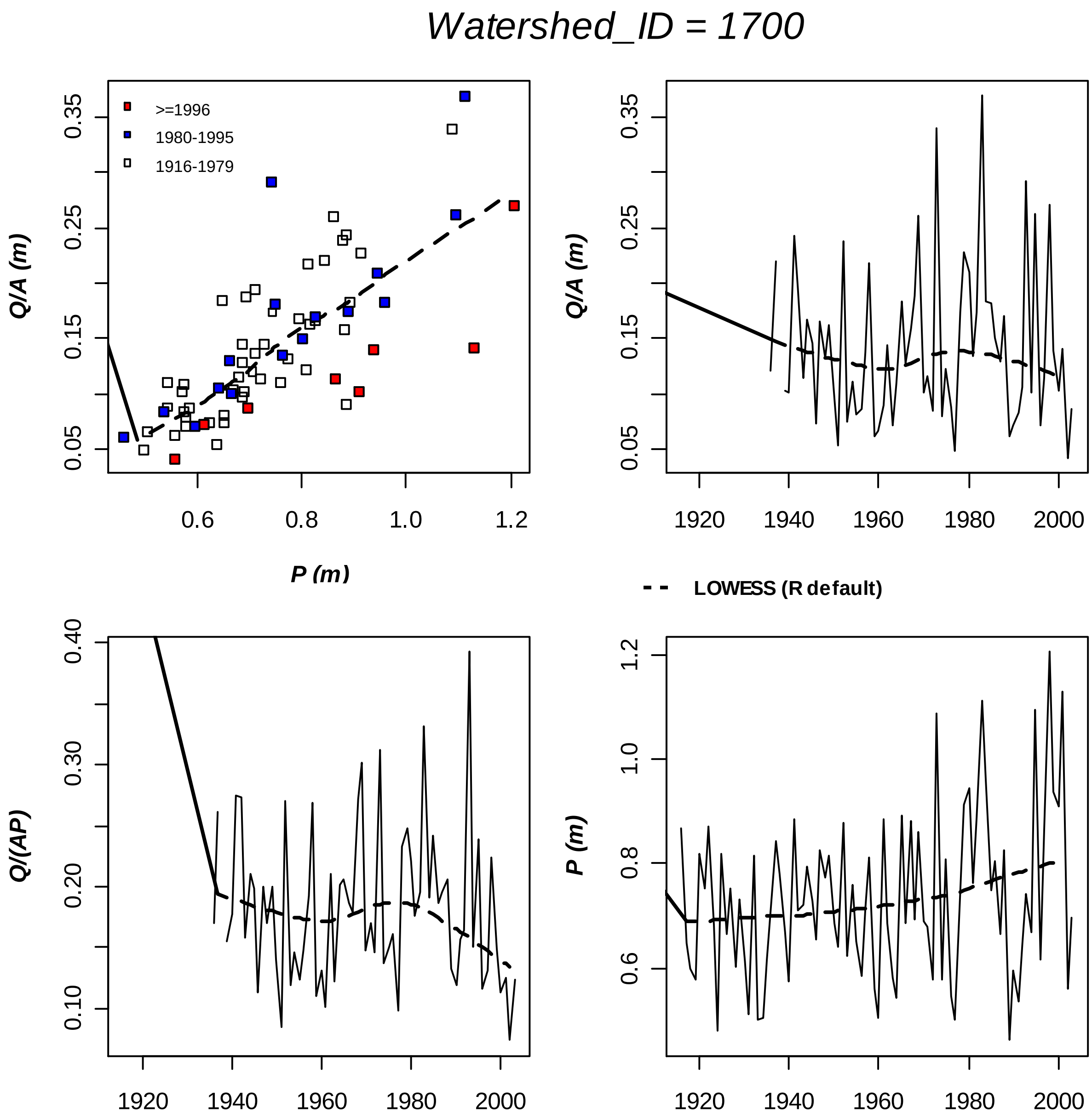

Figure 3.19. *Precipitation and streamflow trend analysis for the Coal Creek near Cedar City watershed (watershed_ID = 1700).*

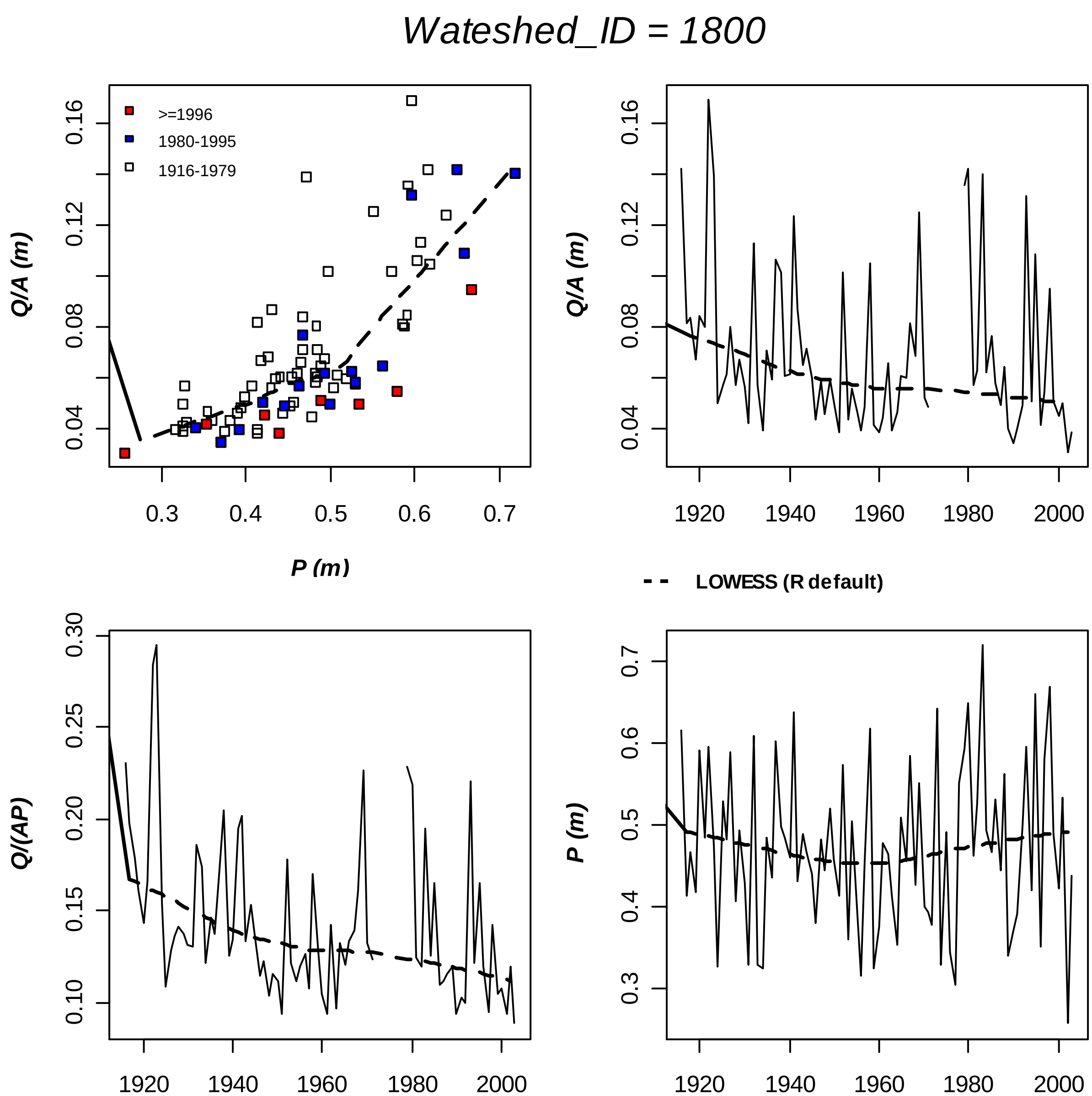

Figure 3.20. *Precipitation and streamflow trend analysis for the Virgin River at Virgin watershed (watershed_ID = 1800).*

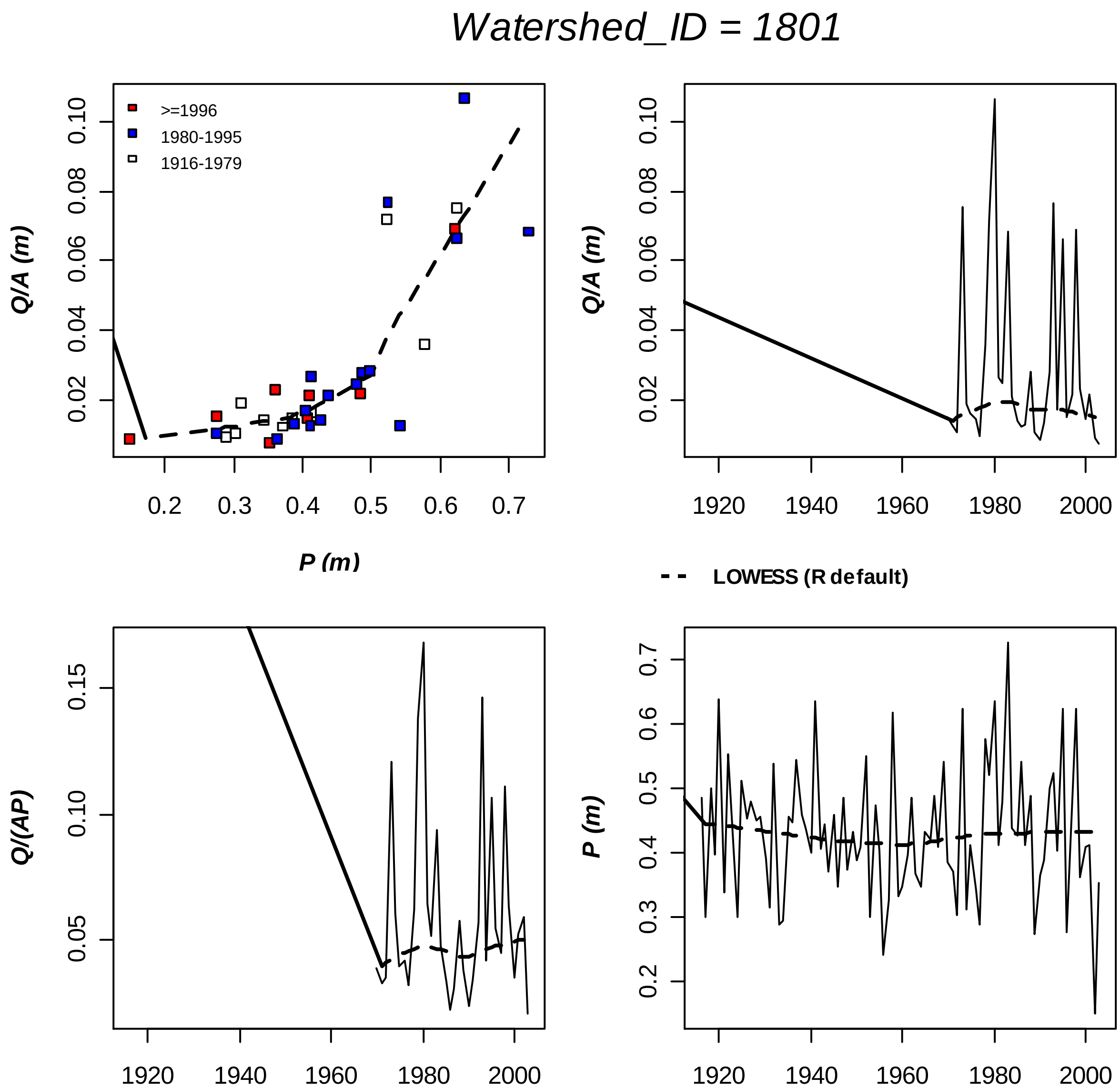

Figure 3.21. *Precipitation and streamflow trend analysis for the Santa Clara River at Gunlock watershed (watershed_ID = 1801).*

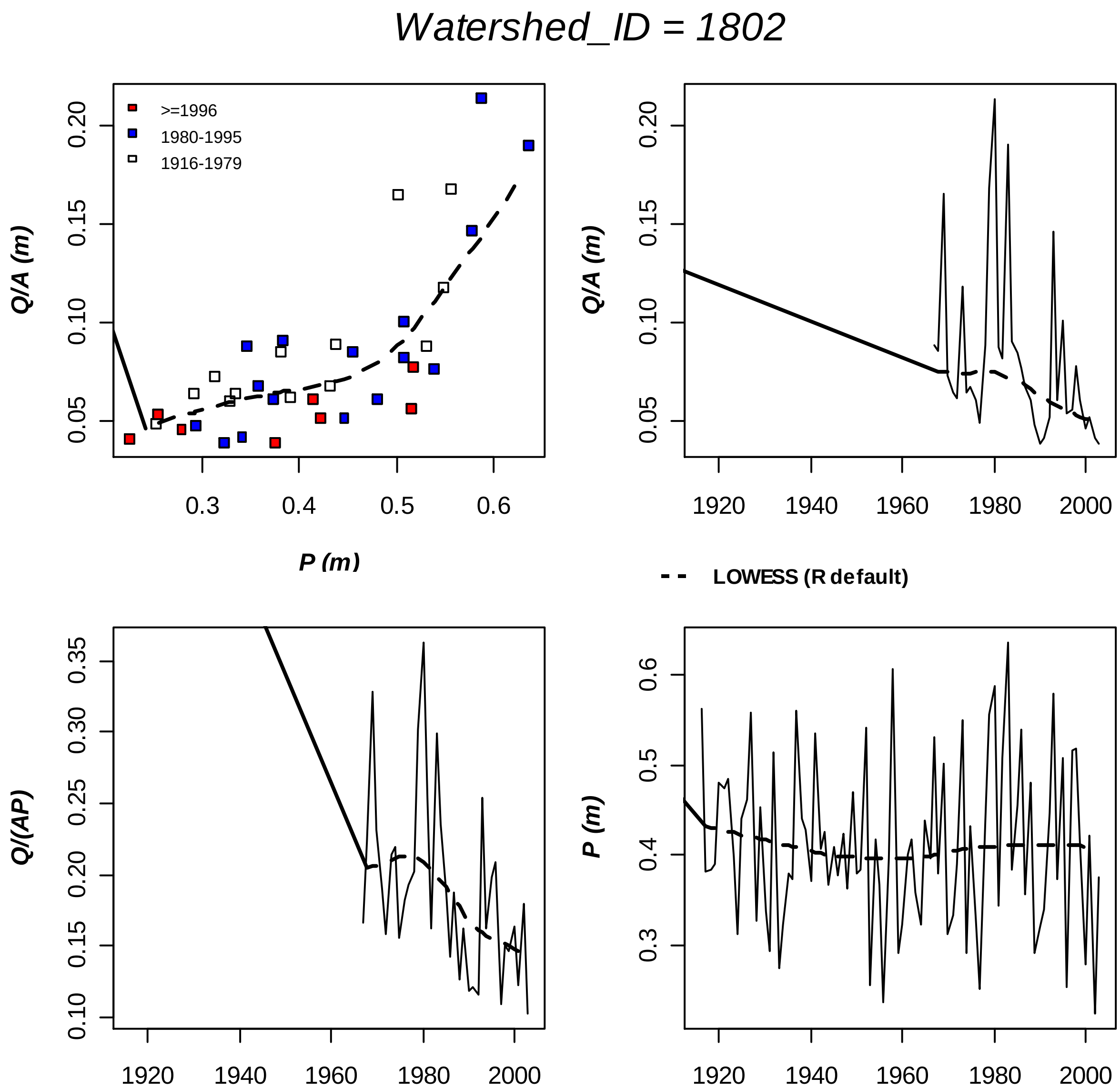

Figure 3.22. *Precipitation and streamflow trend analysis for the East Fork Virgin River near Glendale watershed (watershed_ID = 1802).*

Watershed_ID = 1803

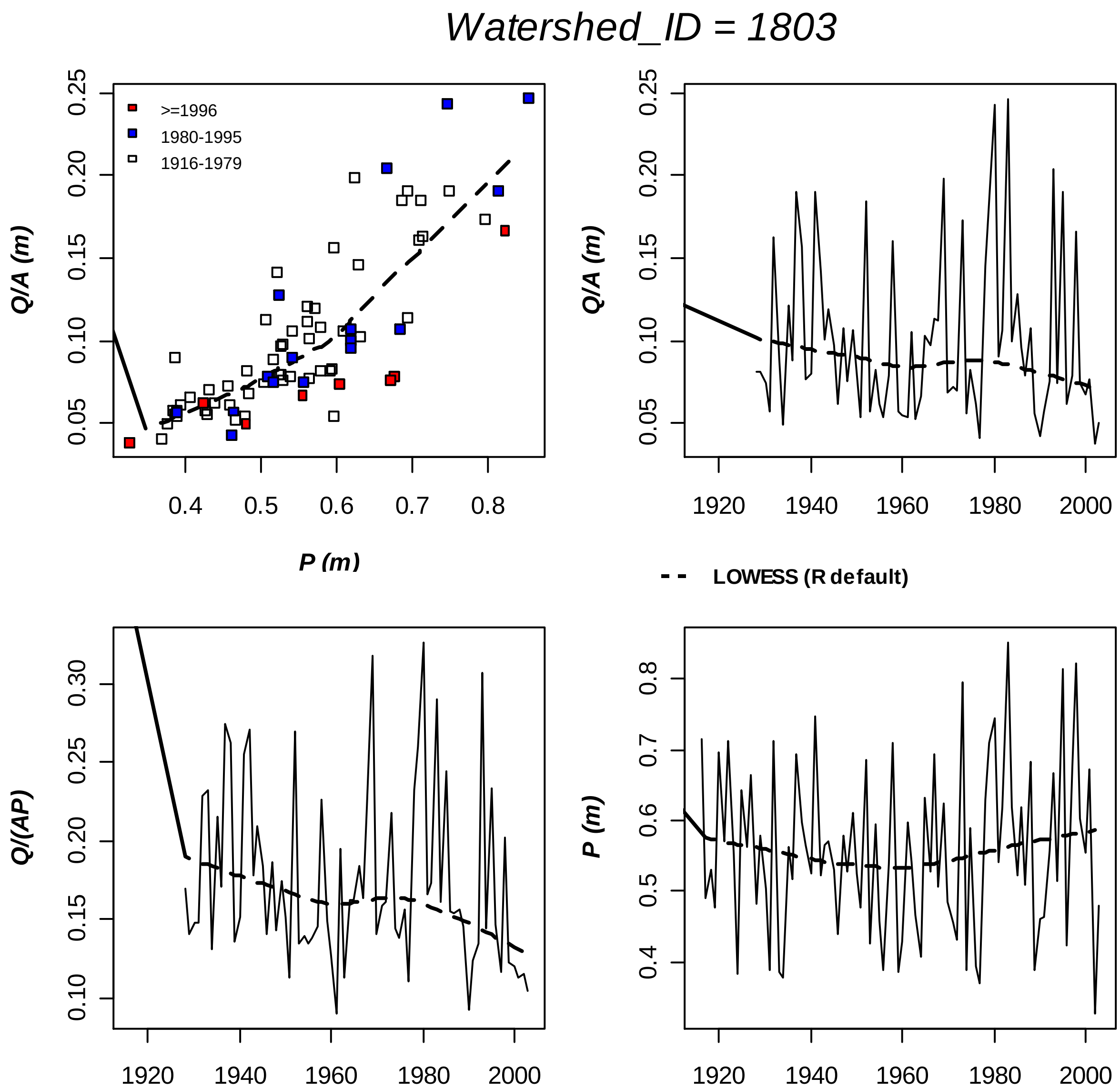

Figure 3.23. *Precipitation and streamflow trend analysis for the North Fork Virgin River near Springdale watershed (watershed_ID = 1803).*

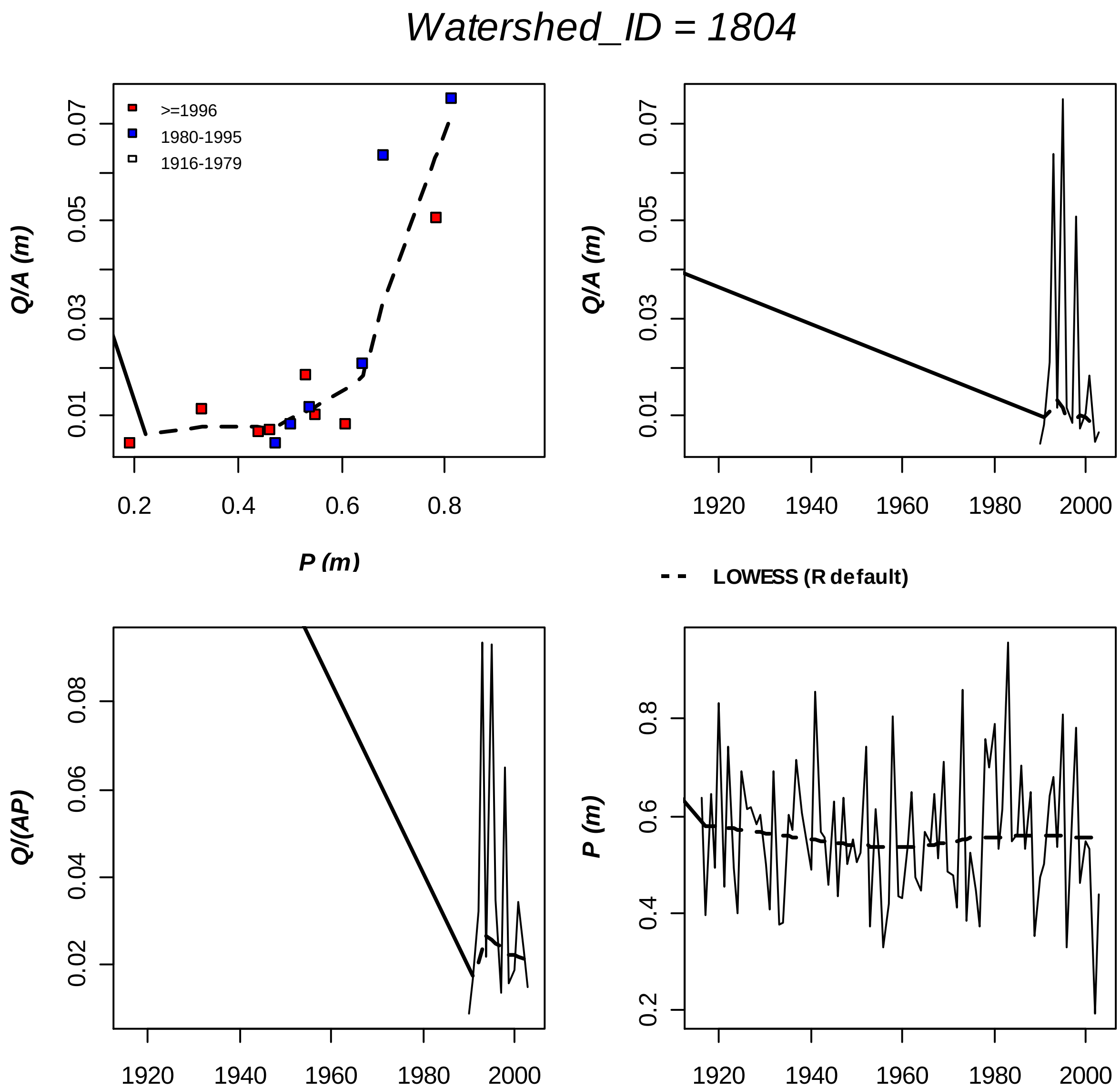

Figure 3.24. *Precipitation and streamflow trend analysis for the Santa Clara River above Baker near Central watershed (watershed_ID = 1804).*

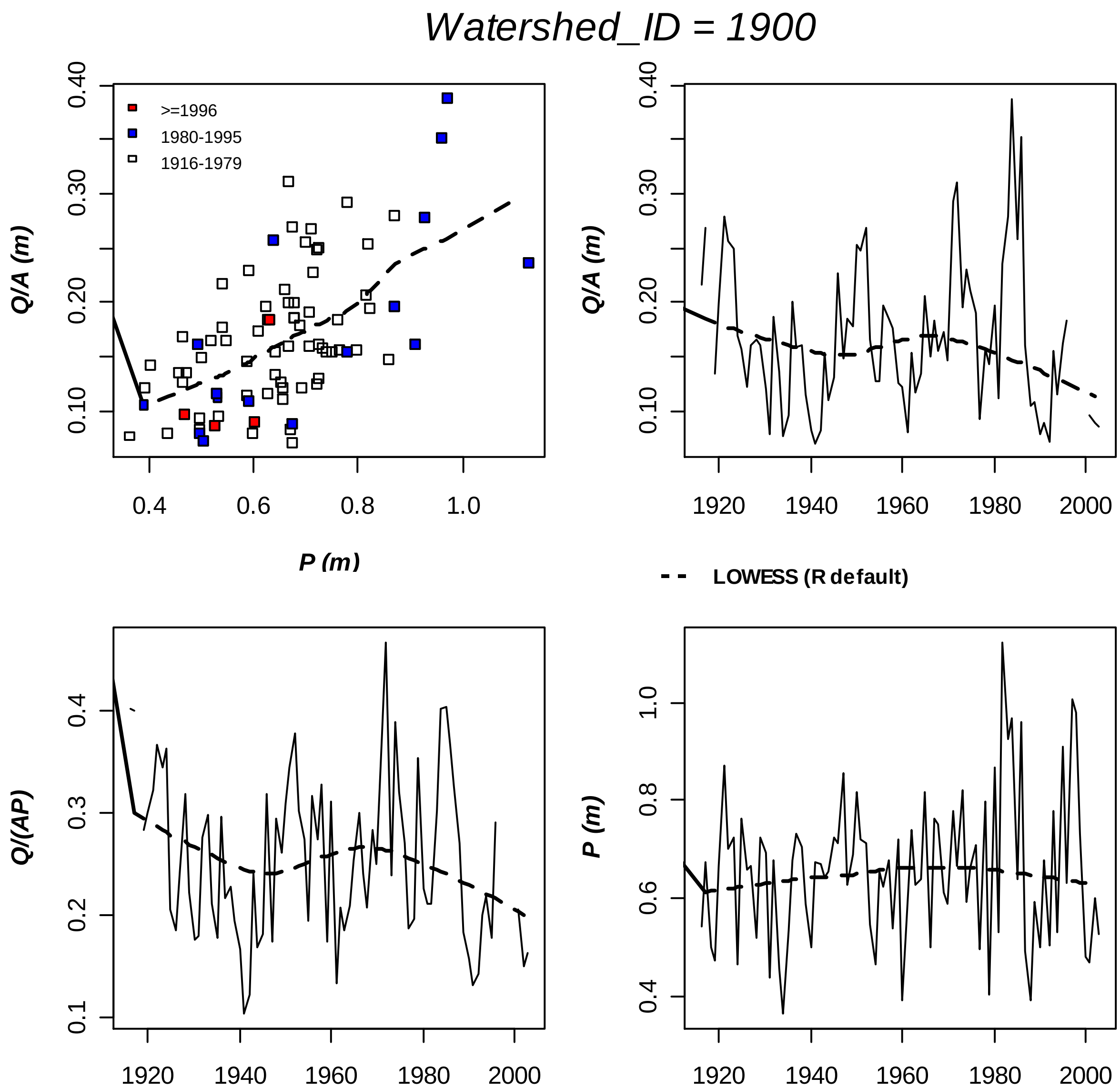

Figure 3.25. *Precipitation and streamflow trend analysis for the Blacksmith Fork near Hyrum watershed (watershed_ID = 1900).*

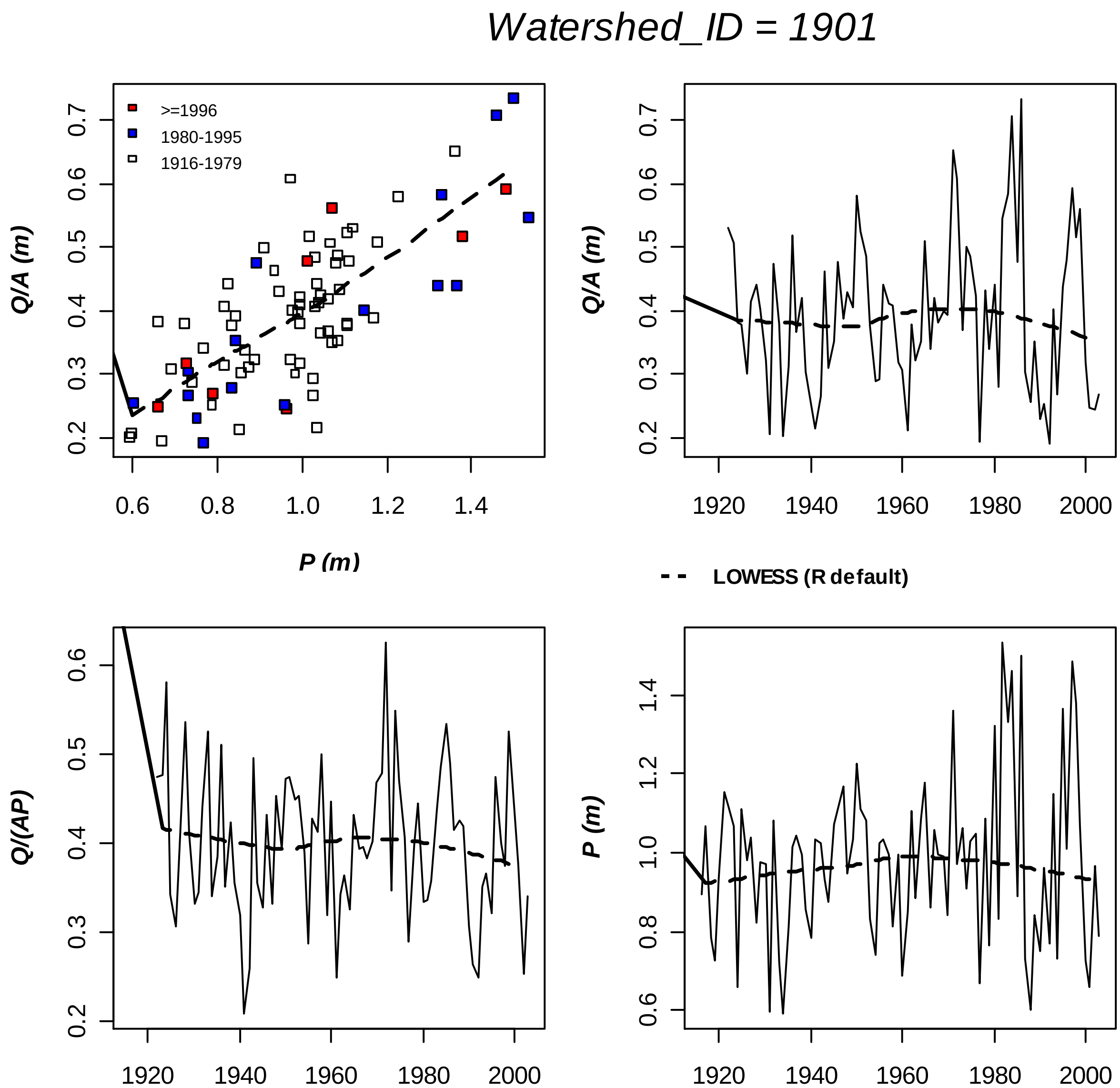

Figure 3.26. *Precipitation and streamflow trend analysis for the Logan River near Logan watershed (watershed_ID = 1901).*

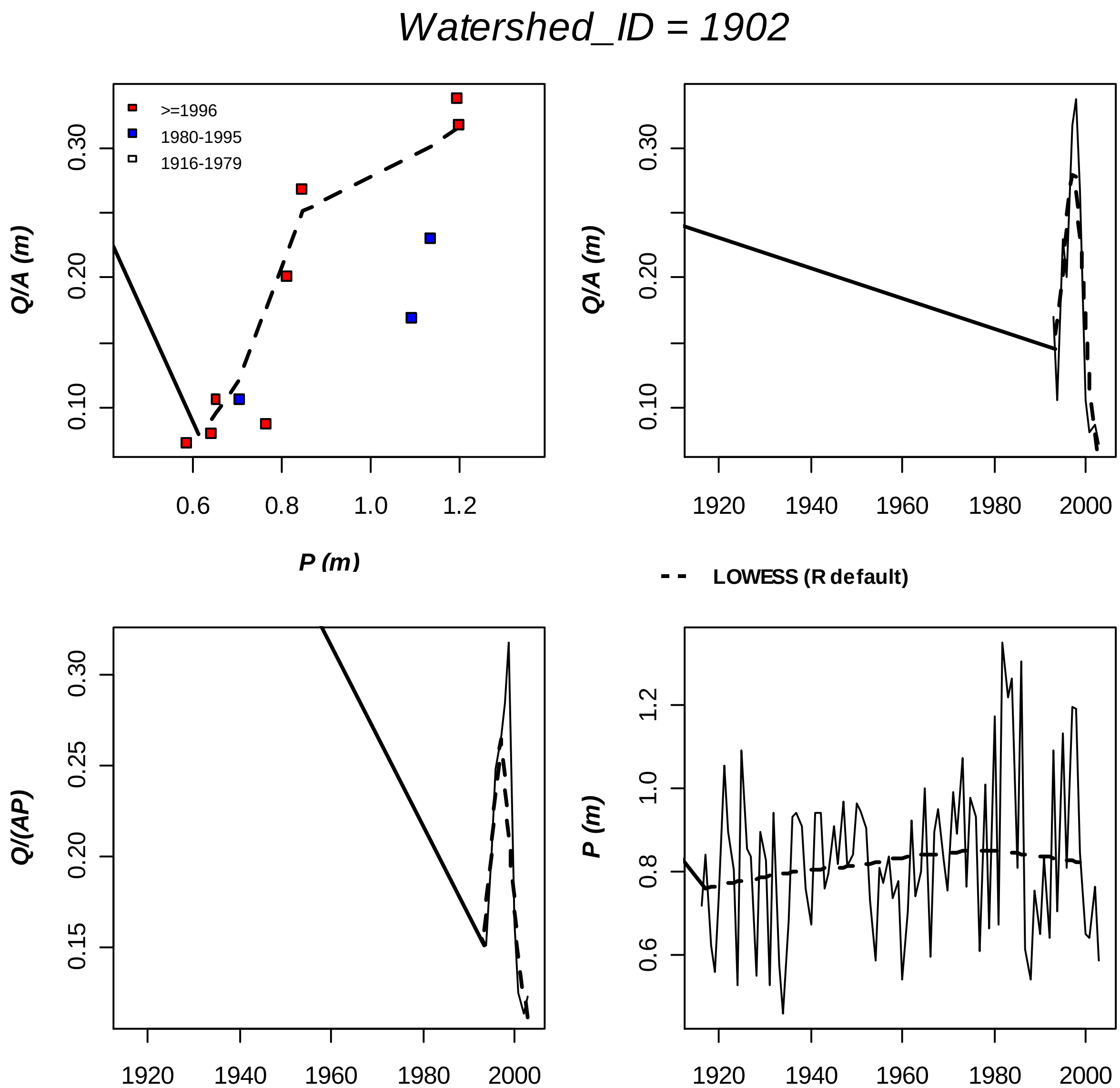

Figure 3.27. *Precipitation and streamflow trend analysis for the Little Bear River at Paradise watershed (watershed_ID = 1902).*

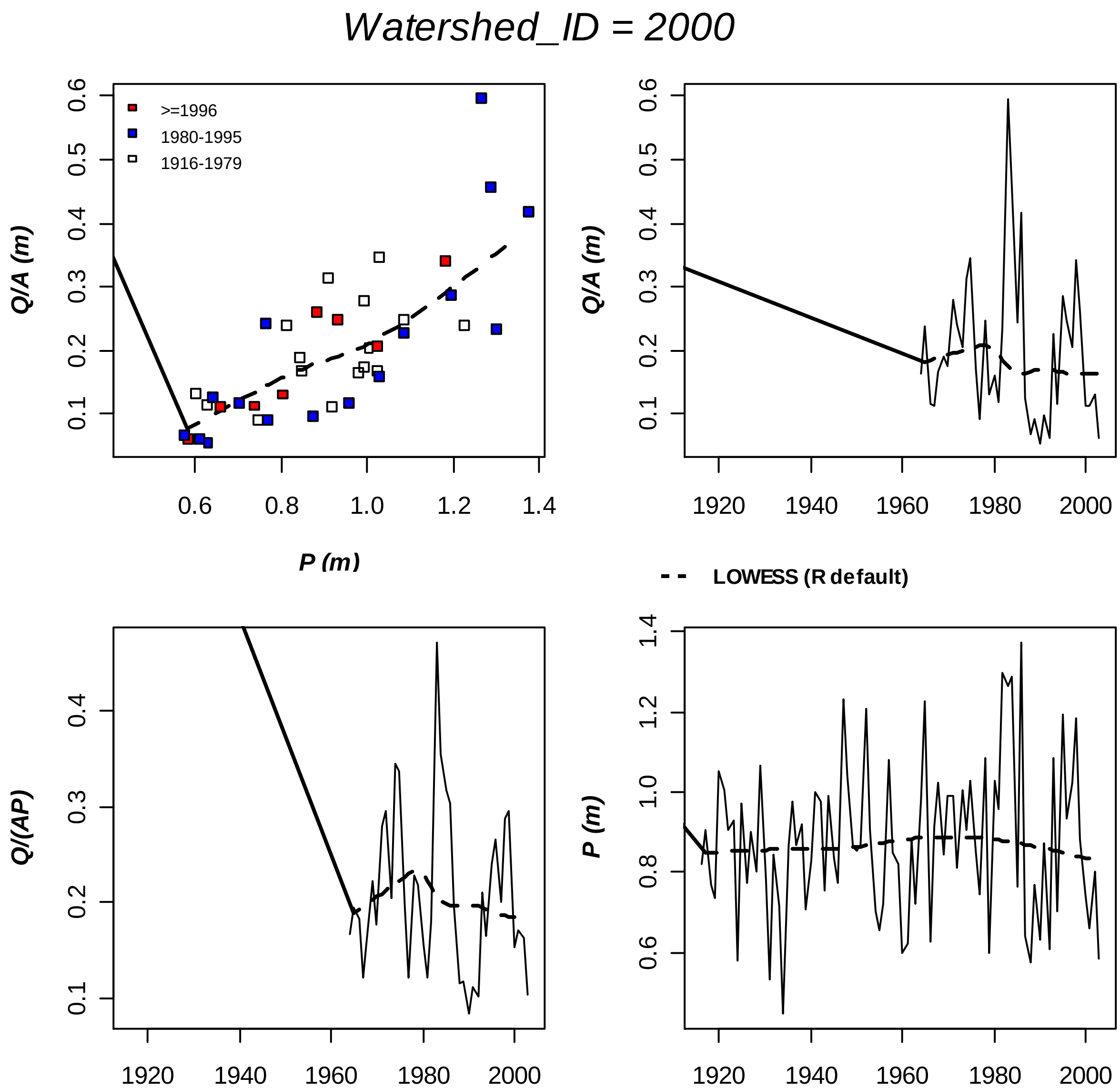

Figure 3.28. *Precipitation and streamflow trend analysis for the Red Butte Creek at Fort Douglas near Salt Lake City watershed (watershed_ID = 2000).*

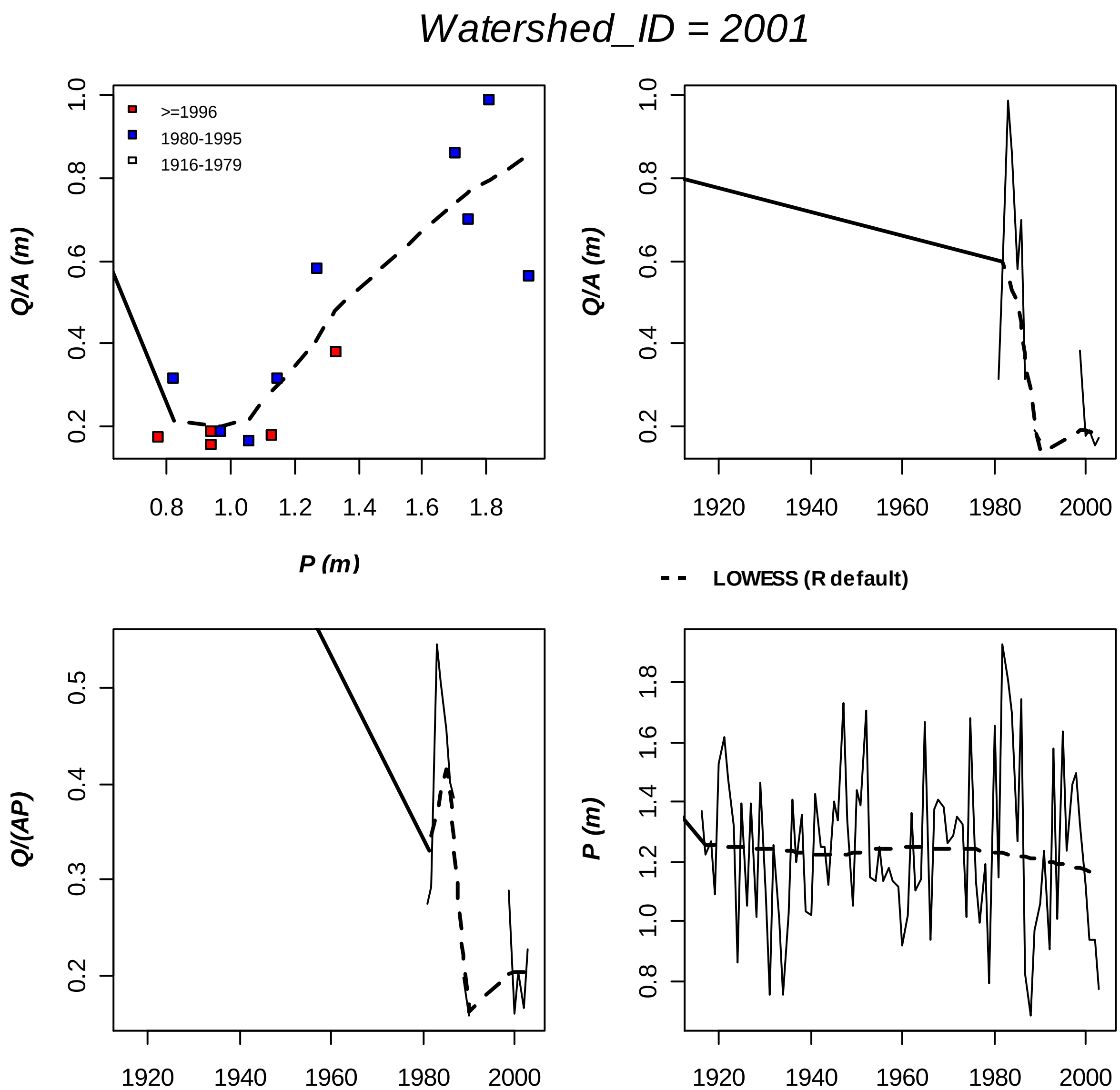

Figure 3.29. *Precipitation and streamflow trend analysis for the Little Cottonwood creek at Jordan River near Salt Lake City watershed (watershed_ID = 2001).*

Watershed_ID = 2002

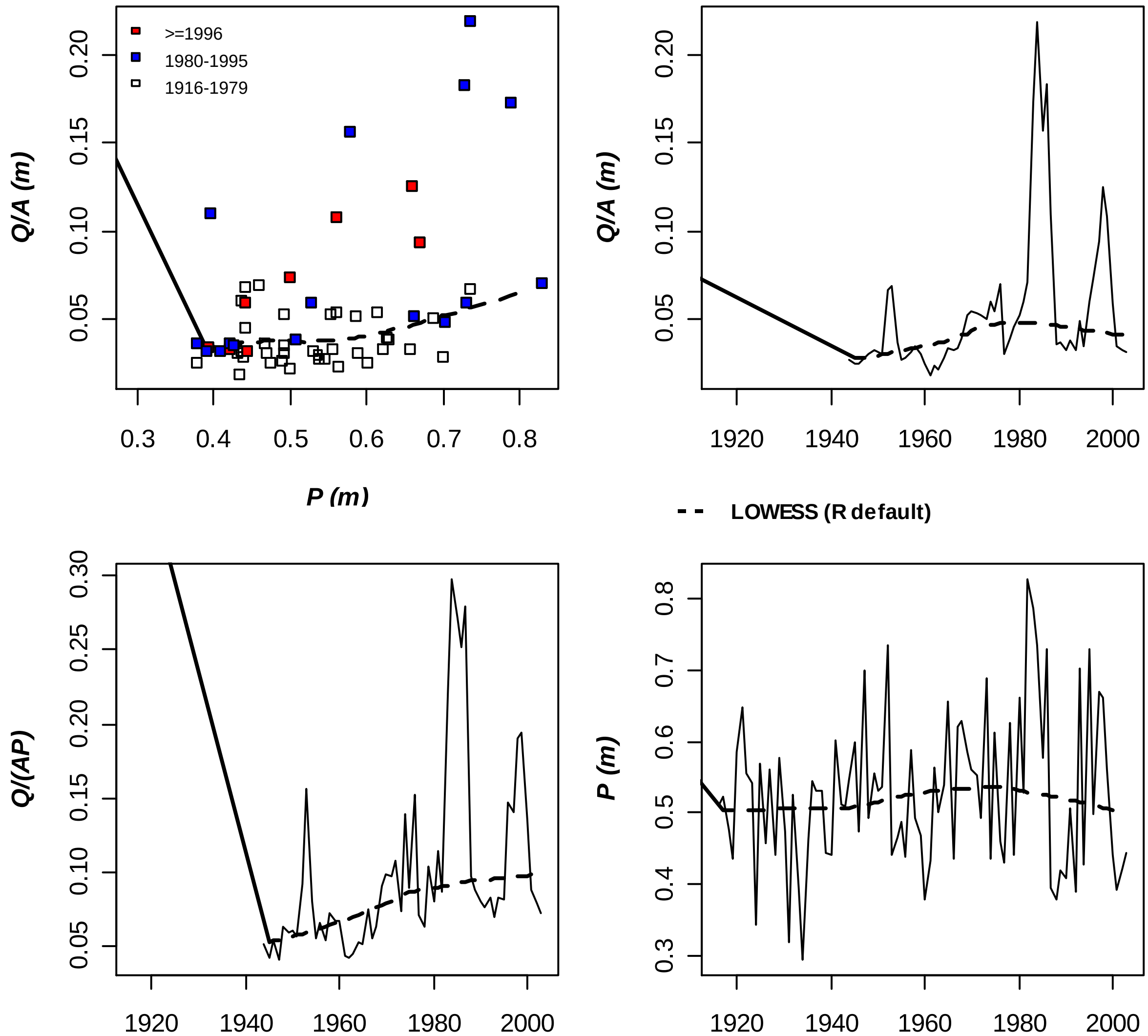

Figure 3.30. *Precipitation and streamflow trend analysis for the Jordan River & Surplus Canal at Salt Lake City watershed (watershed_ID = 2002).*

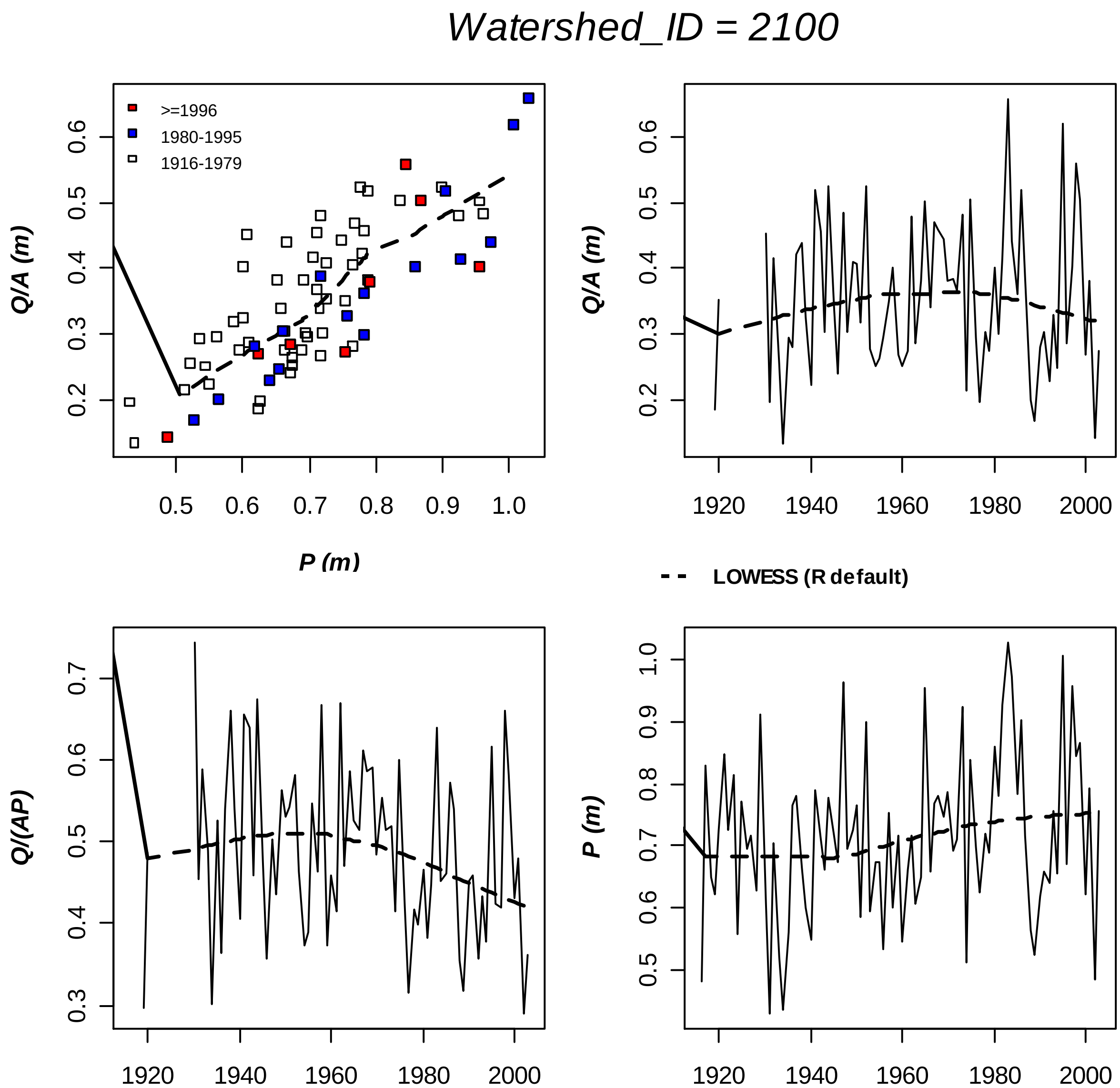

Figure 3.31. *Precipitation and streamflow trend analysis for the Whiterocks River near Whiterocks watershed (watershed_ID = 2100).*

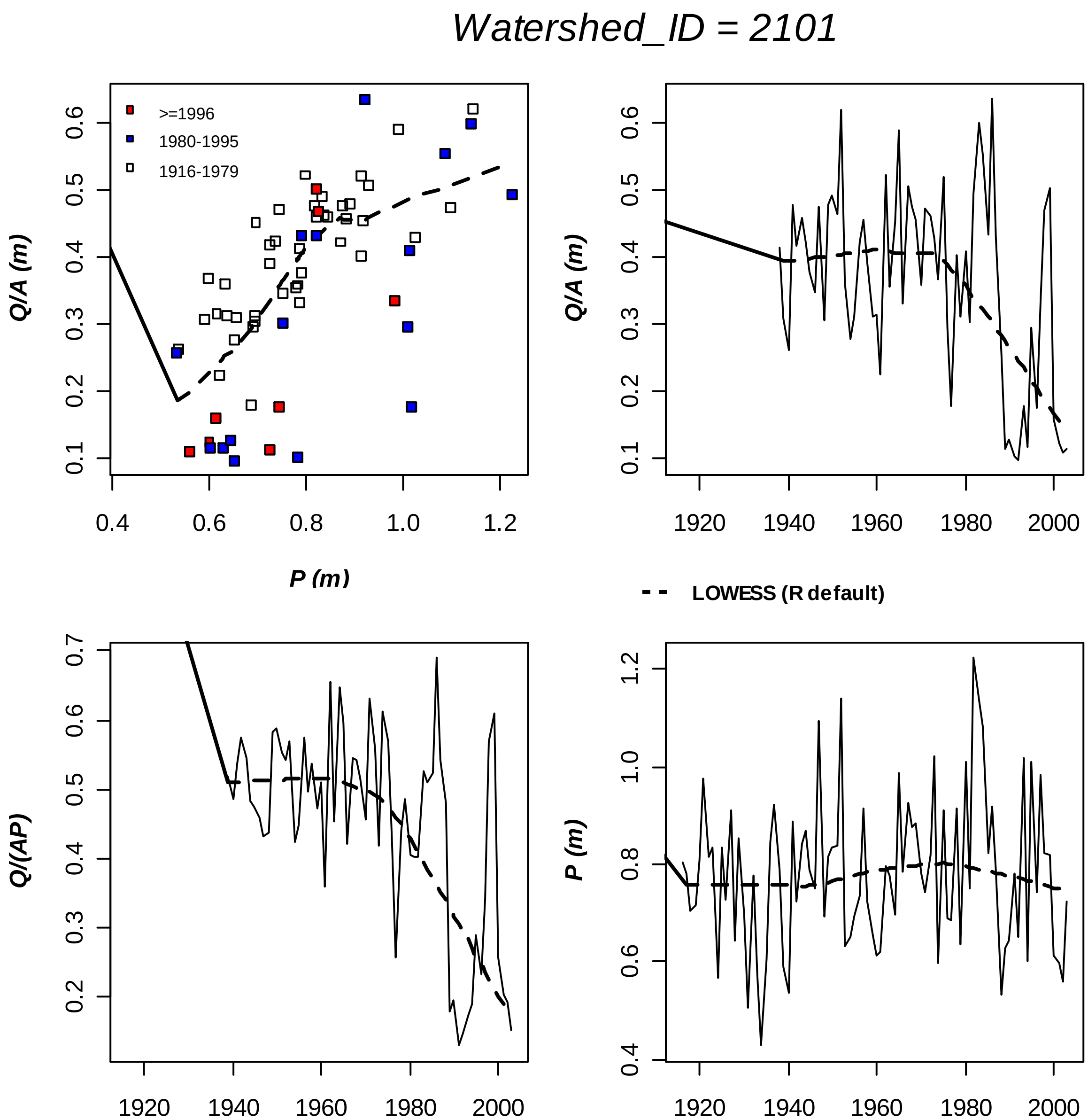

Figure 3.32. *Precipitation and streamflow trend analysis for the Rock Creek near Mountain Home watershed (watershed_ID = 2101).*

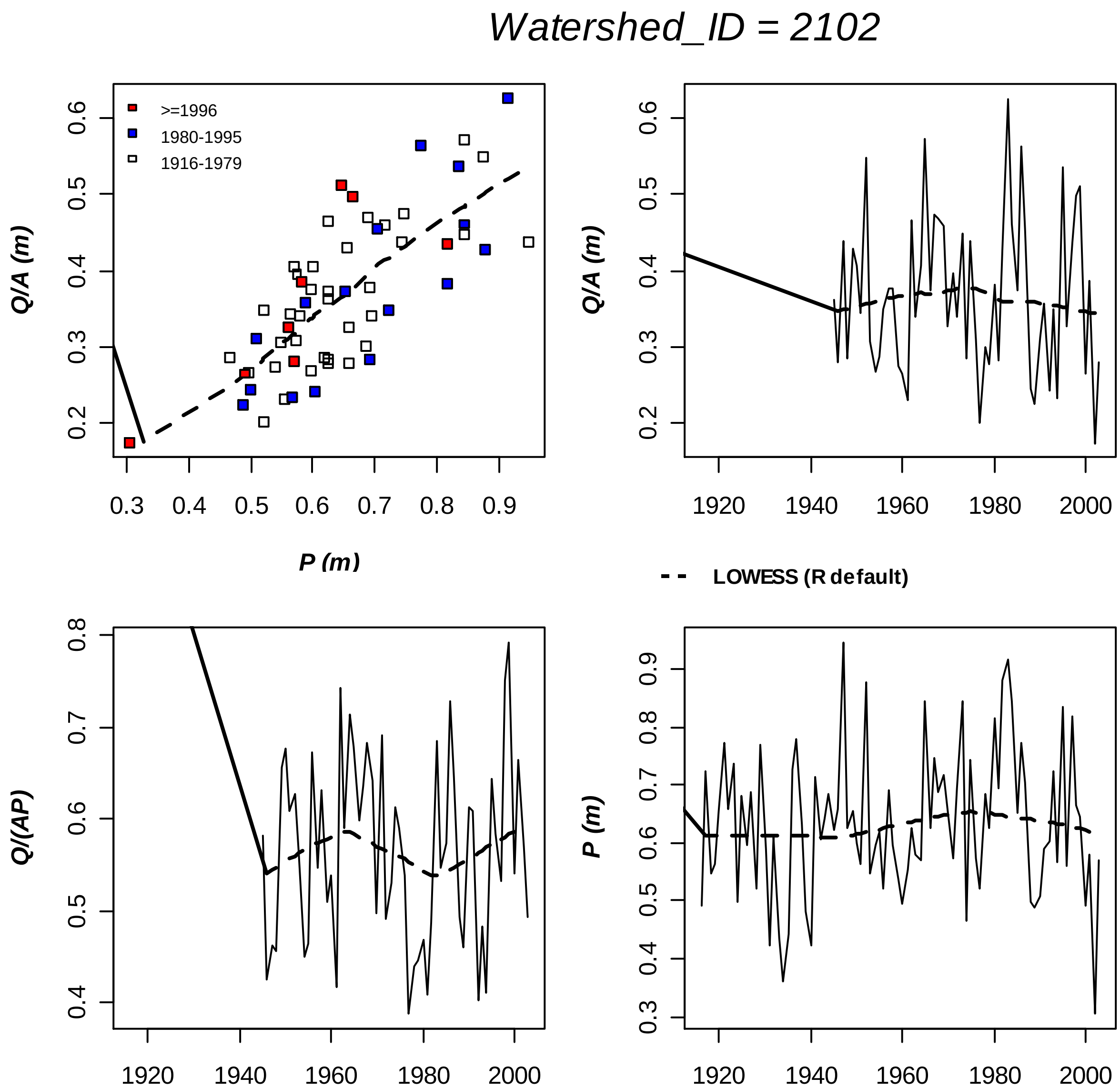

Figure 3.33. *Precipitation and streamflow trend analysis for the Yellowstone River near Altonah watershed (watershed_ID = 2102).*

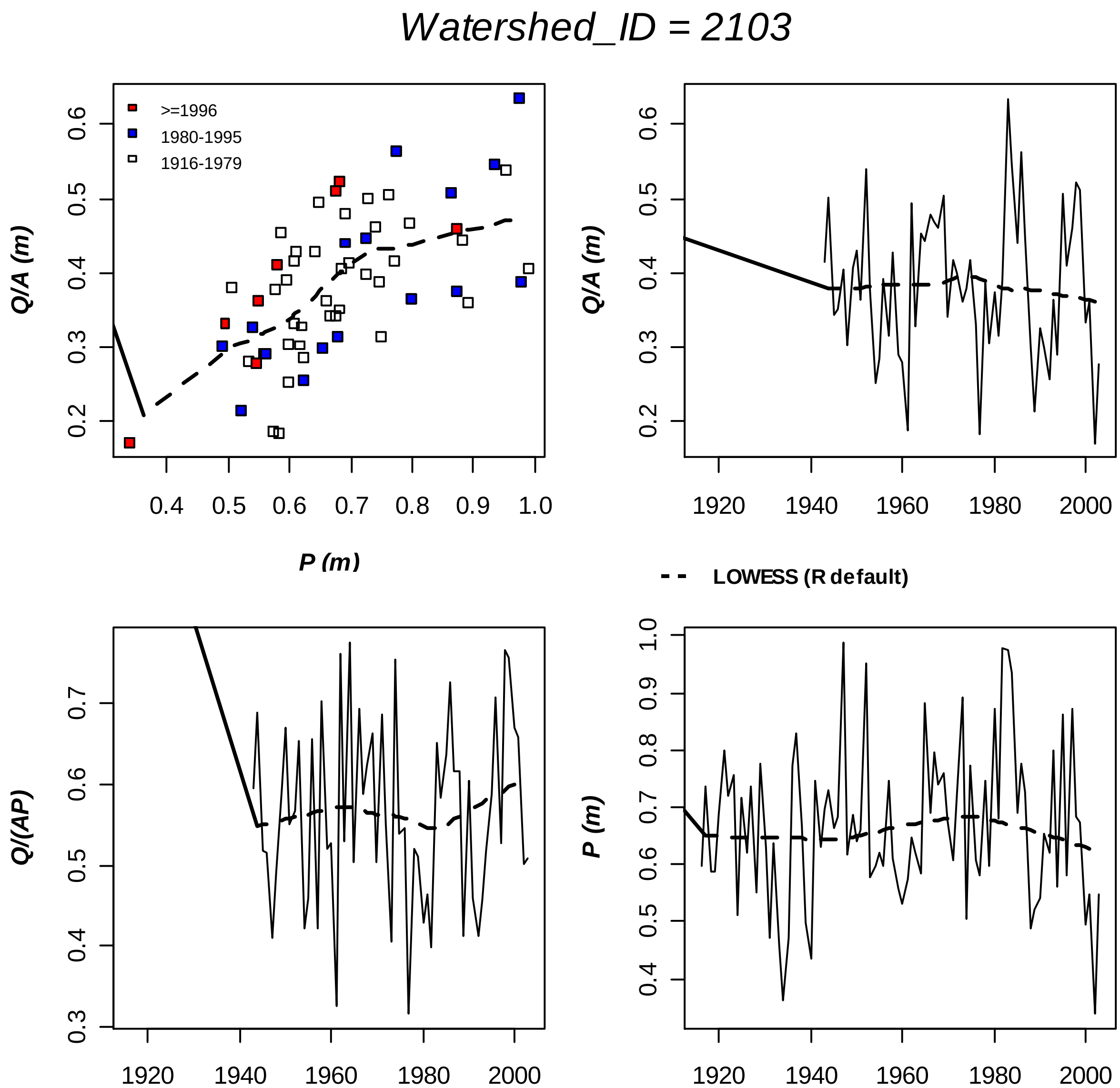

Figure 3.34. *Precipitation and streamflow trend analysis for the Lake Fork River below Moon Lake near Mountain Home watershed (watershed_ID = 2103).*

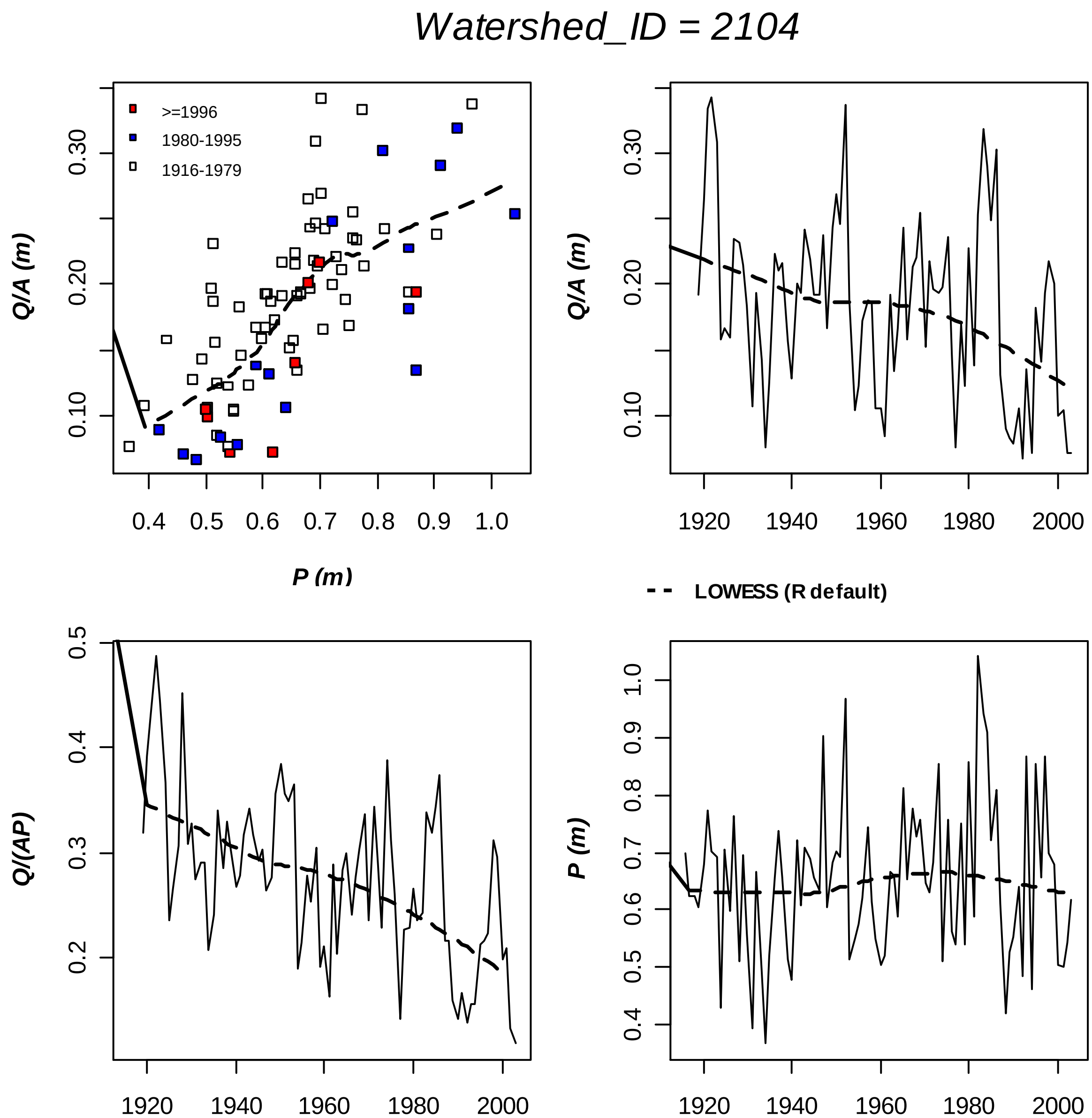

Figure 3.35. *Precipitation and streamflow trend analysis for the Duchesne River near Tabiona watershed (watershed_ID = 2104).*

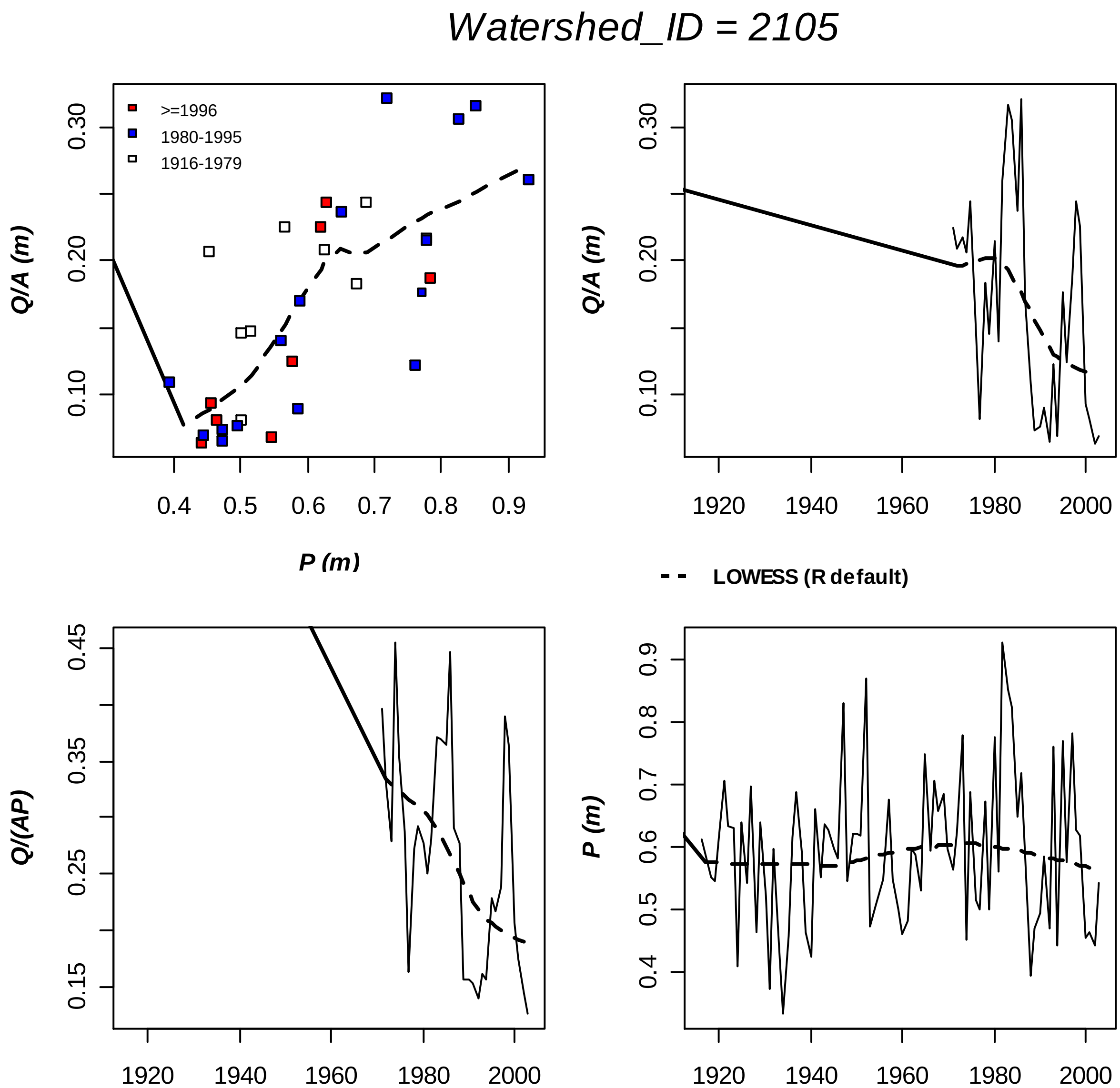

Figure 3.36. *Precipitation and streamflow trend analysis for the Duchesne River above Knight Diversion near Duchesne watershed (watershed_ID = 2105).*

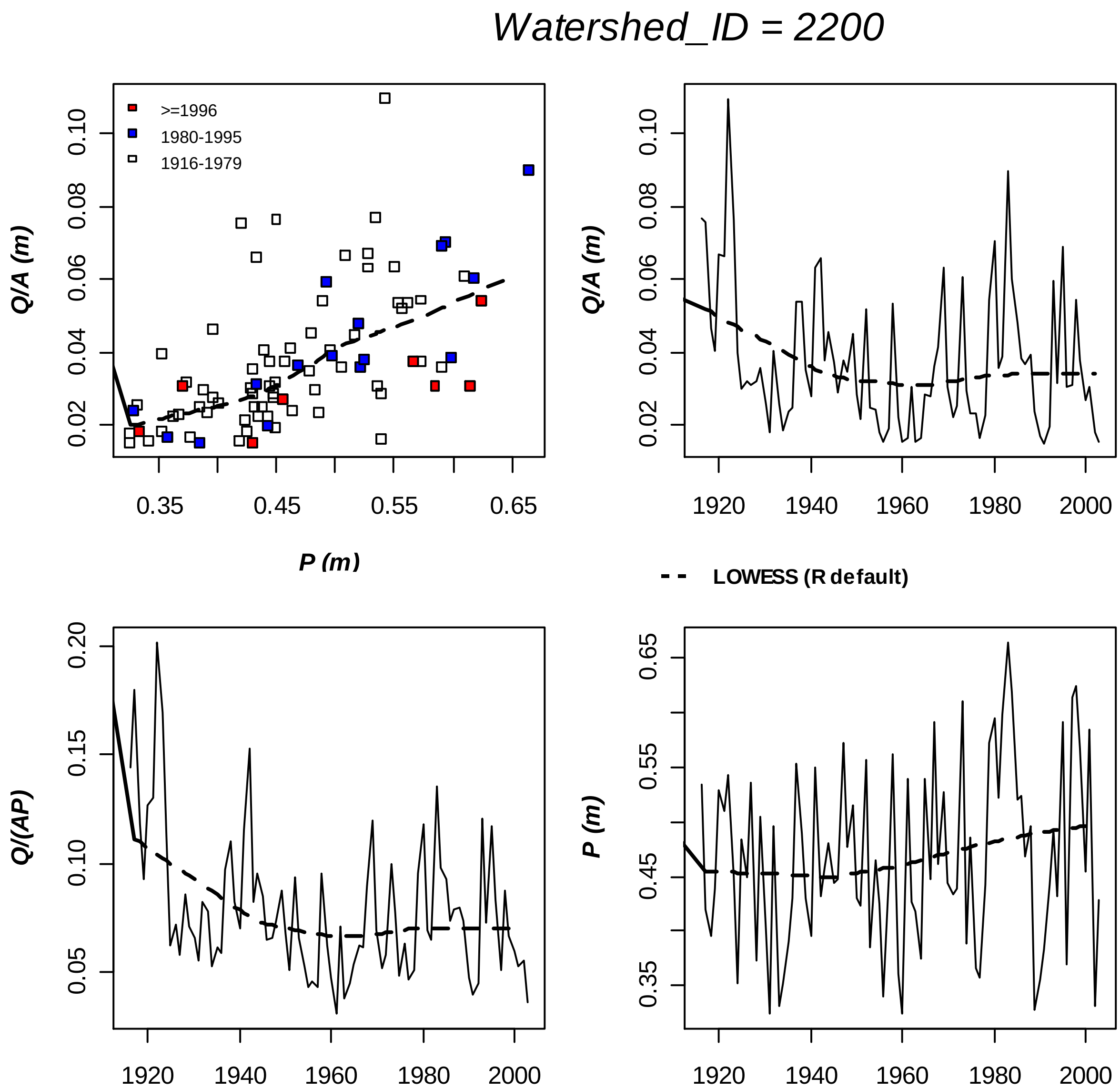

Figure 3.37. *Precipitation and streamflow trend analysis for the Sevier River near Kingston watershed (watershed_ID = 2200).*

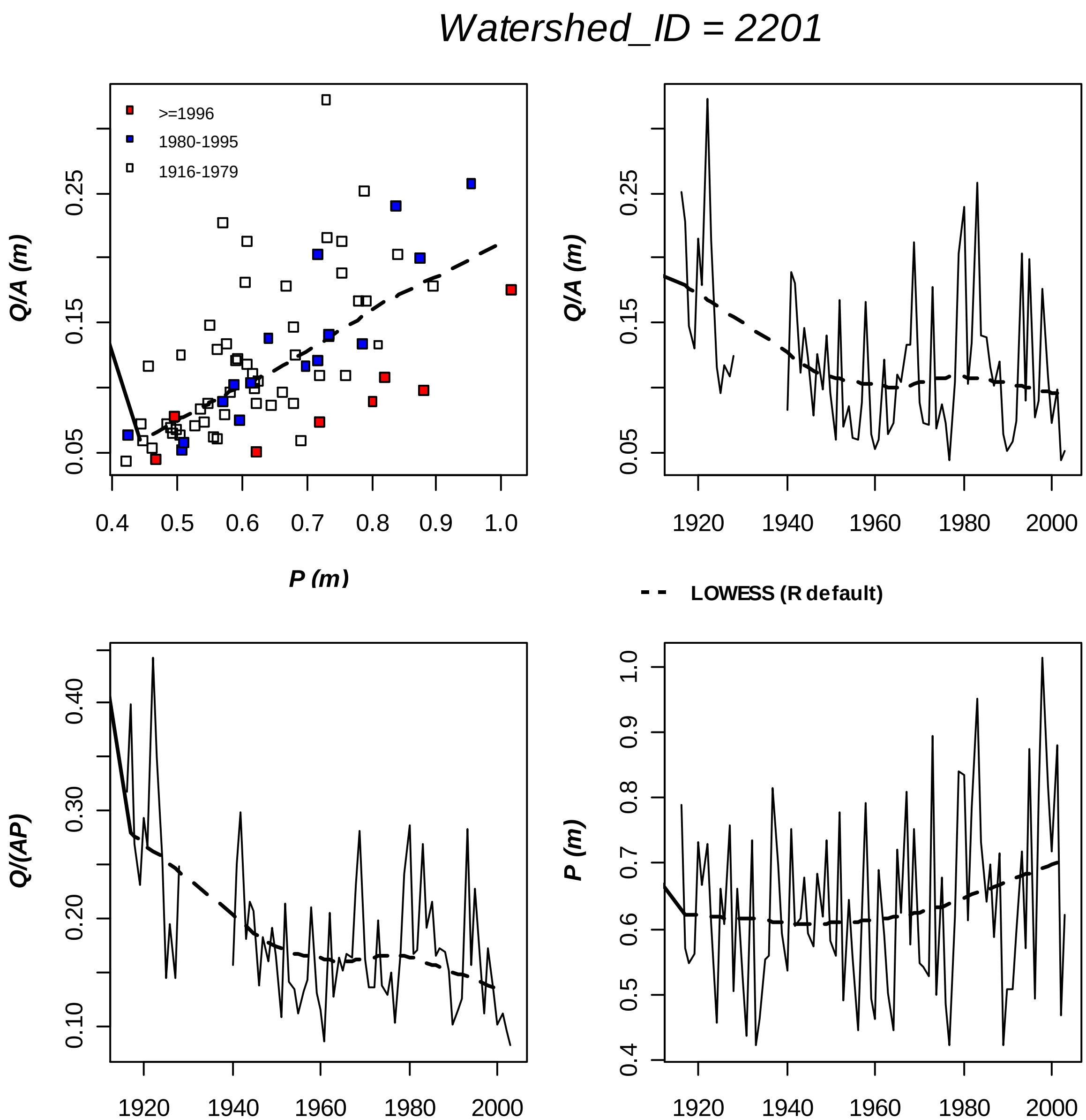

Figure 3.38. *Precipitation and streamflow trend analysis for the Sevier River at Hatch watershed (watershed_ID = 2201).*

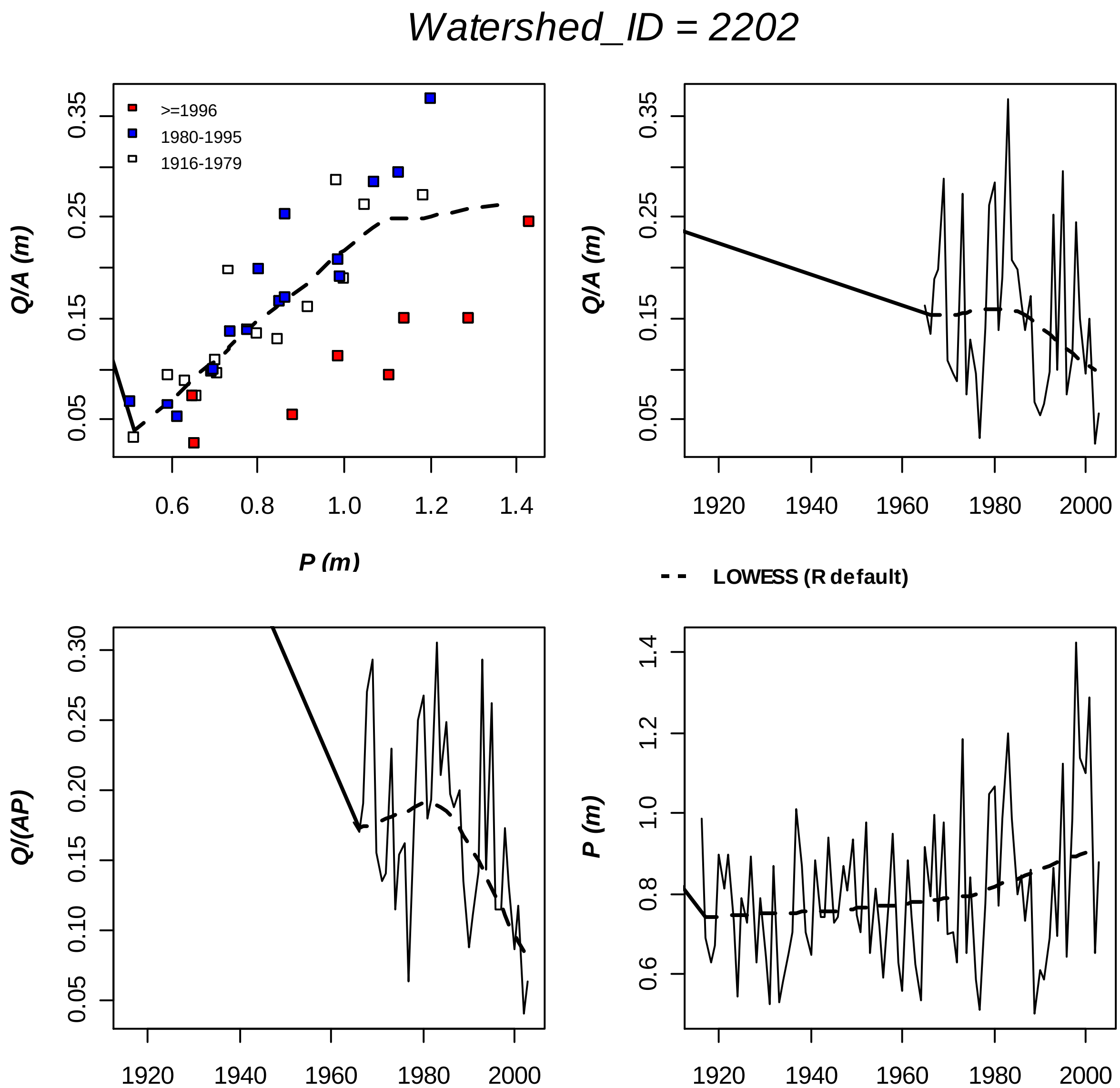

Figure 3.39. *Precipitation and streamflow trend analysis for the Mammoth Creek above west Hatch ditch near Hatch watershed (watershed_ID = 2202).*

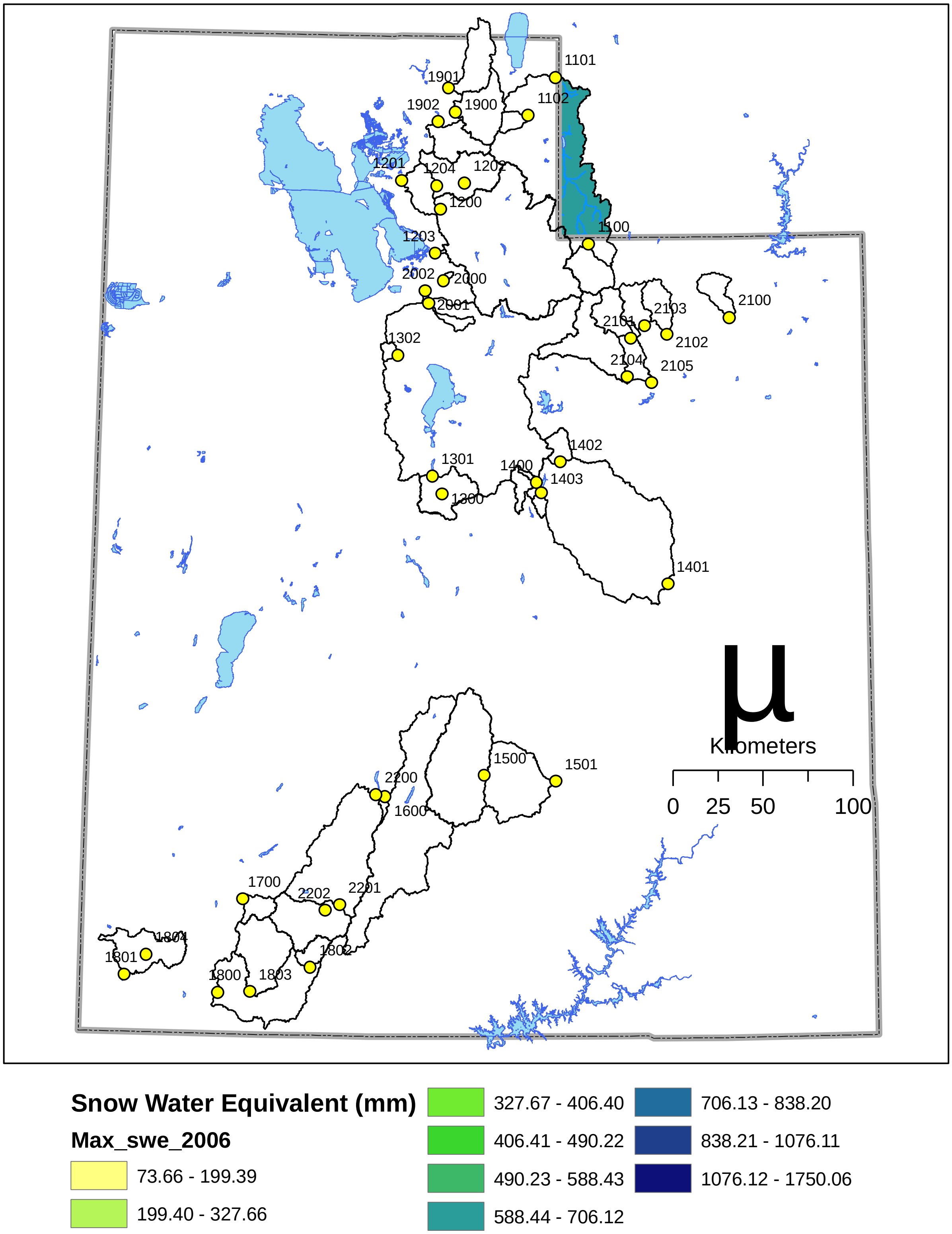

Figure 4. *2006 Maximum Snow Water Equivalent for study watersheds.*

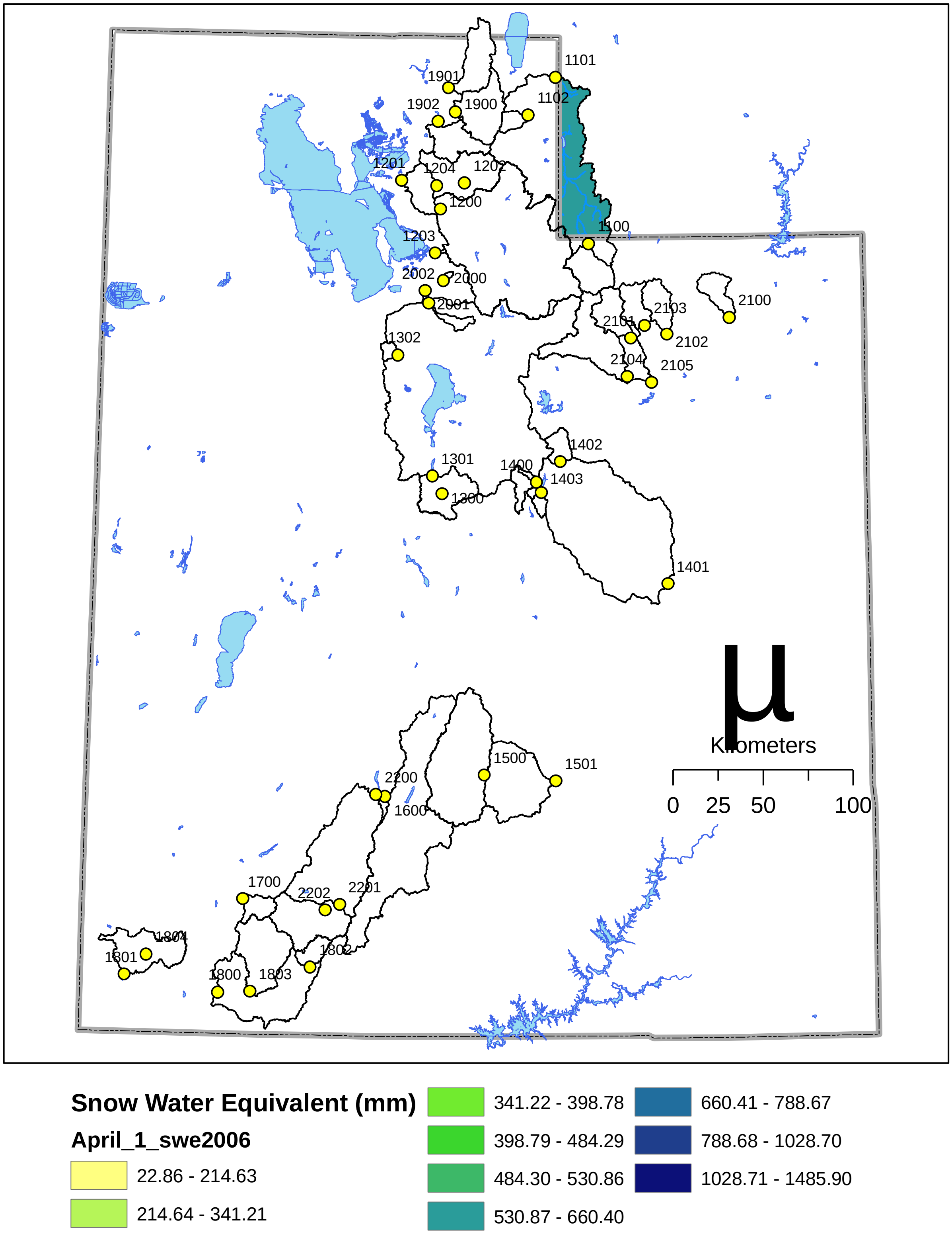

Figure 5. *2006 April 1st Snow Water Equivalent for study watersheds.*

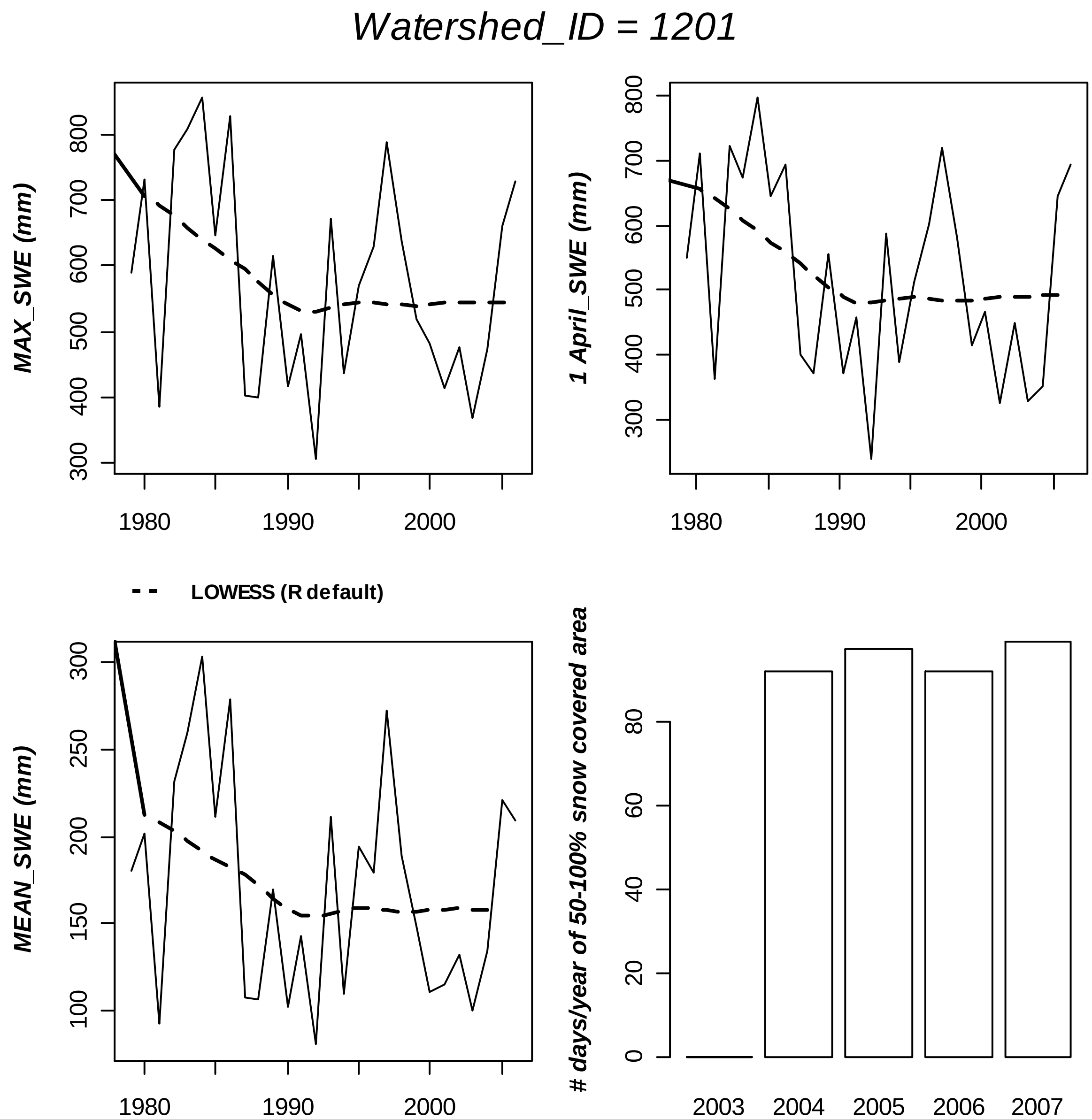

Figure 6.1. *Snowfall analyses for Weber River near Plain City watershed (watershed_ID = 1201). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

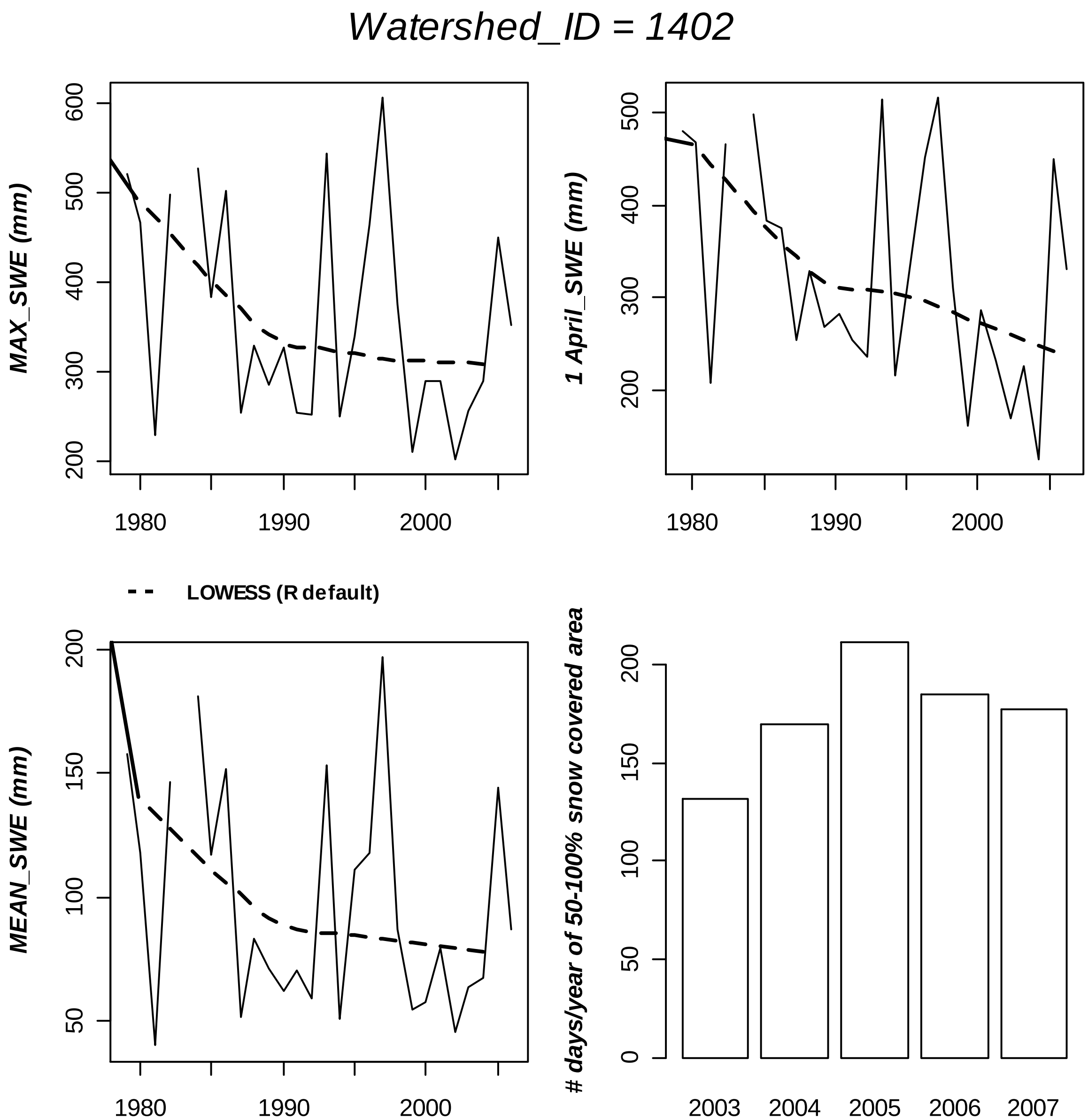

Figure 6.2. *Snowfall analyses for White River BL Tabbyune CRK near Soldier Summit watershed (watershed_ID = 1402). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year. Note: the snow covered area data is taken from Price River - Scofield Res. - Nr Scofield)*

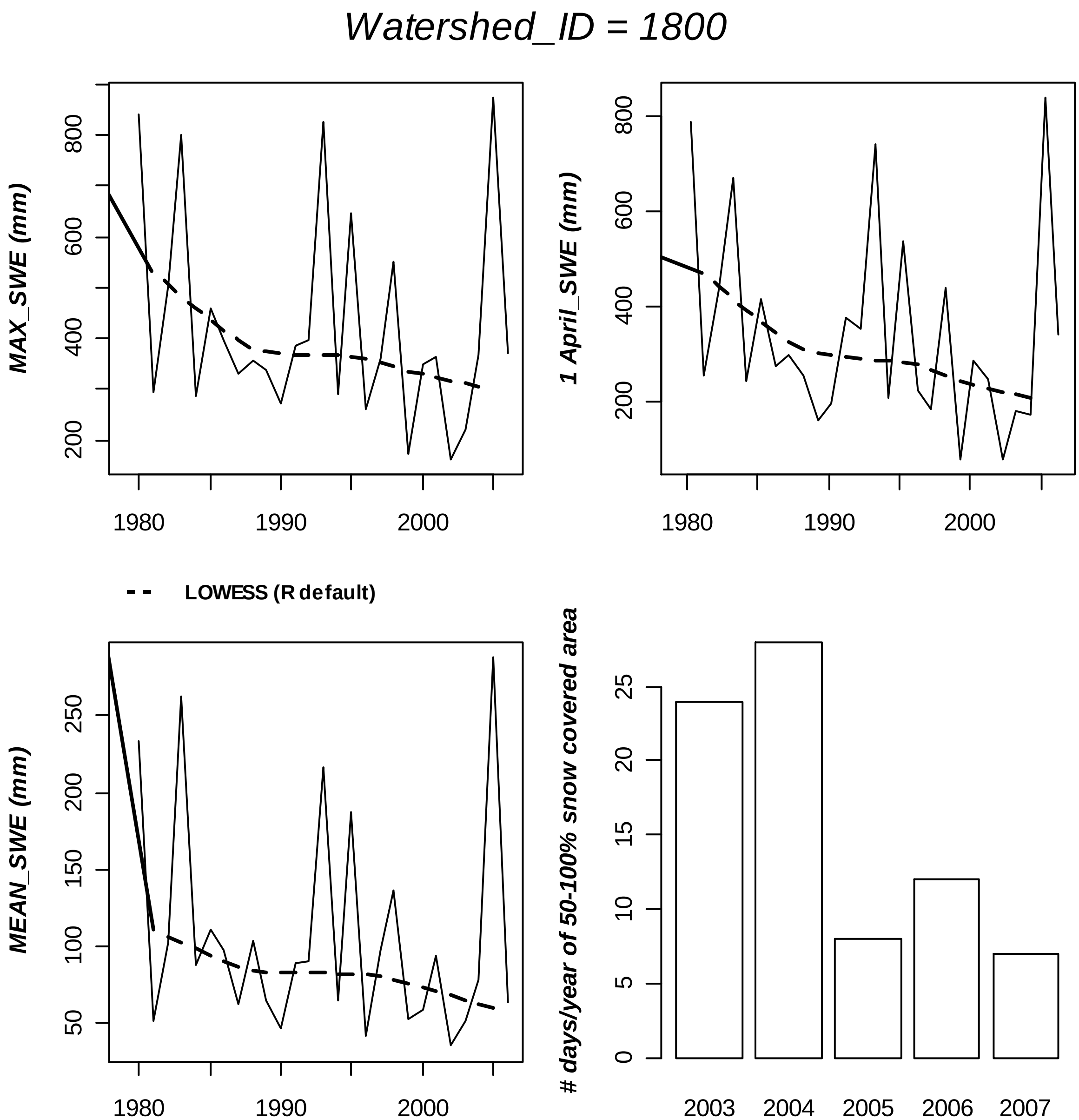

Figure 6.3. *Snowfall analyses for Virgin River at Virgin watershed (watershed_ID = 1800). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

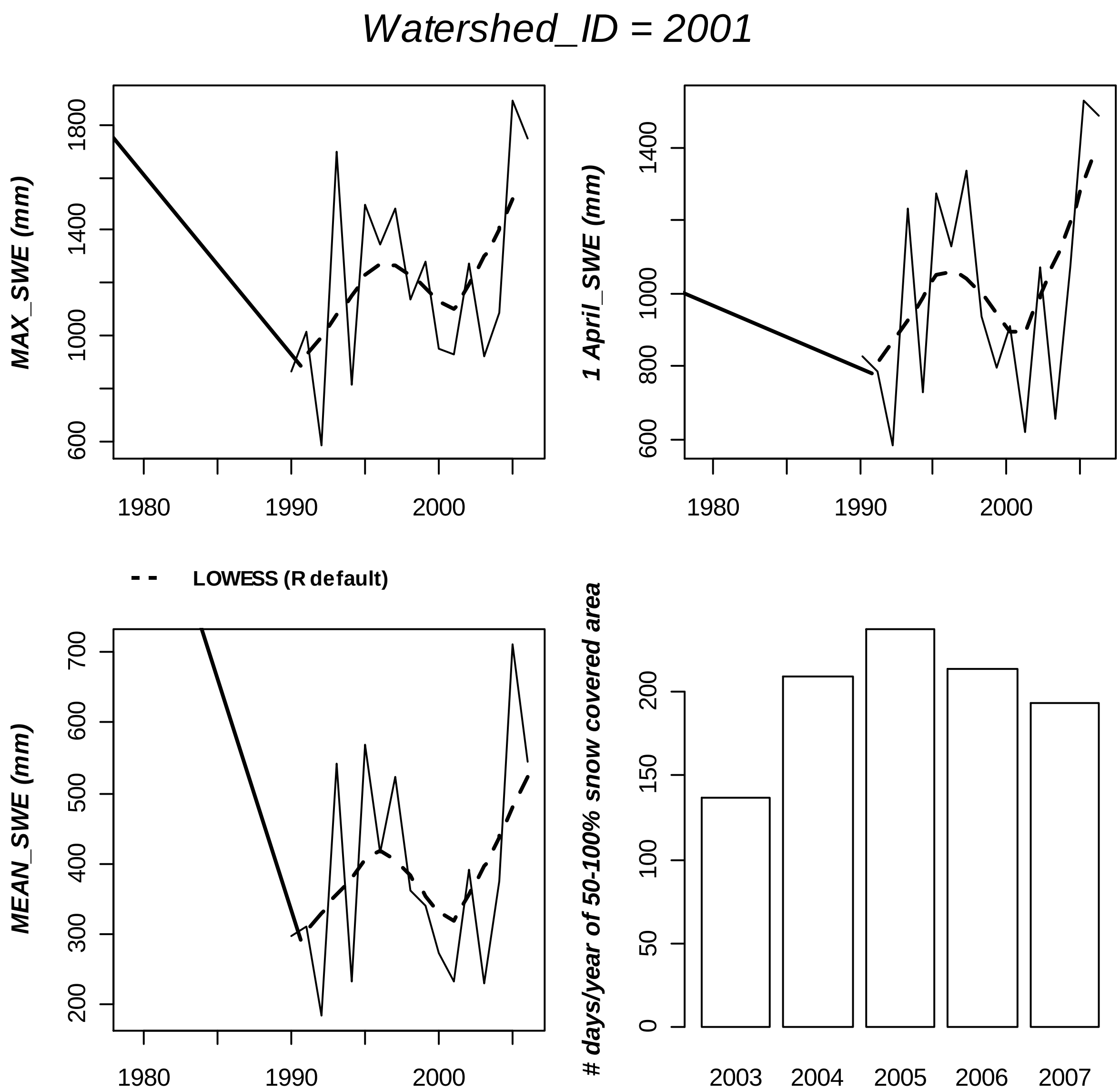

Figure 6.4. *Snowfall analyses for Little Cottonwood creek at Jordan River near Salt Lake City watershed (watershed_ID = 2001). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

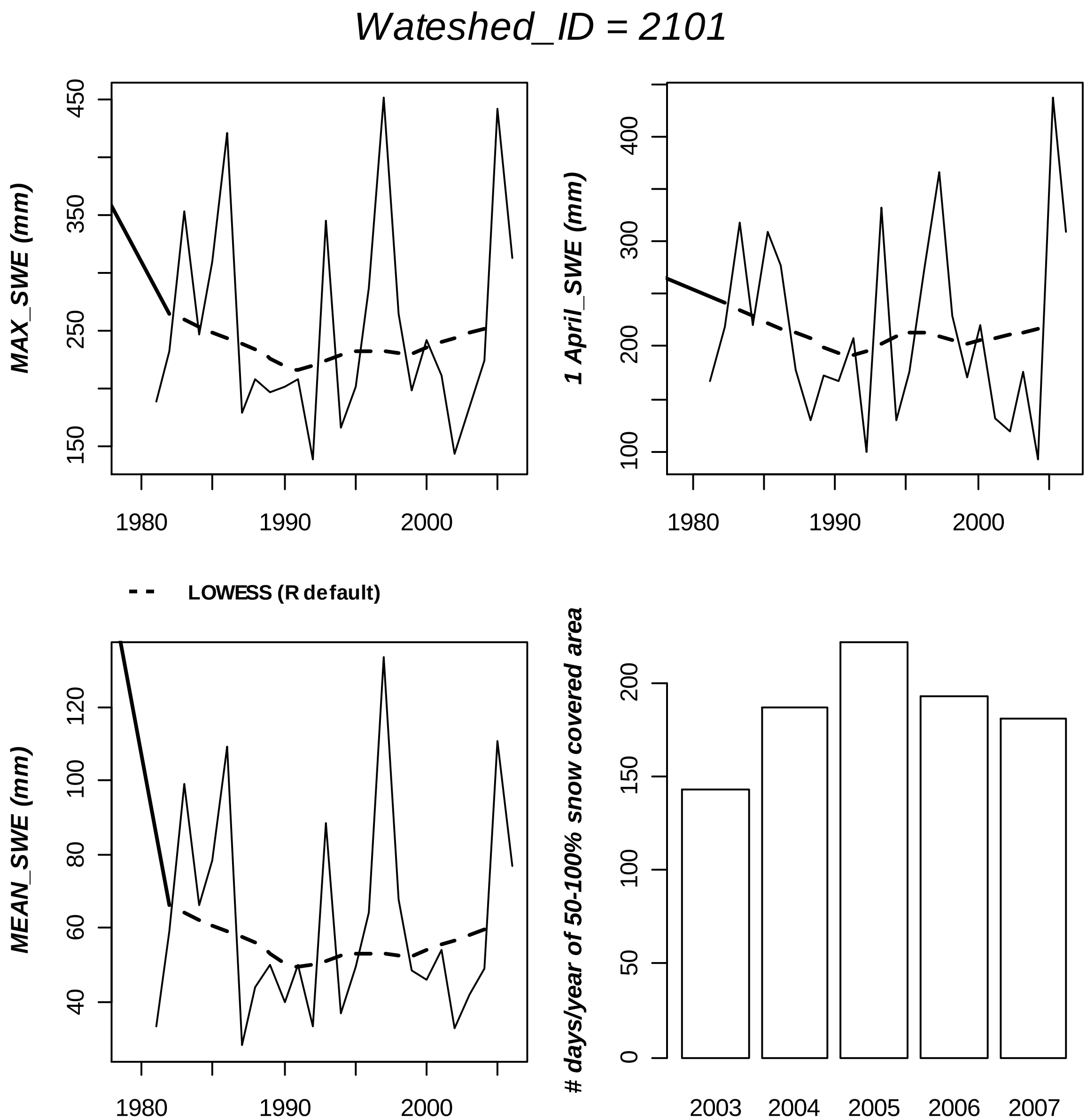

Figure 6.5. *Snowfall analyses for Rock Creek near Mountain Home watershed (watershed_ID = 2101). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

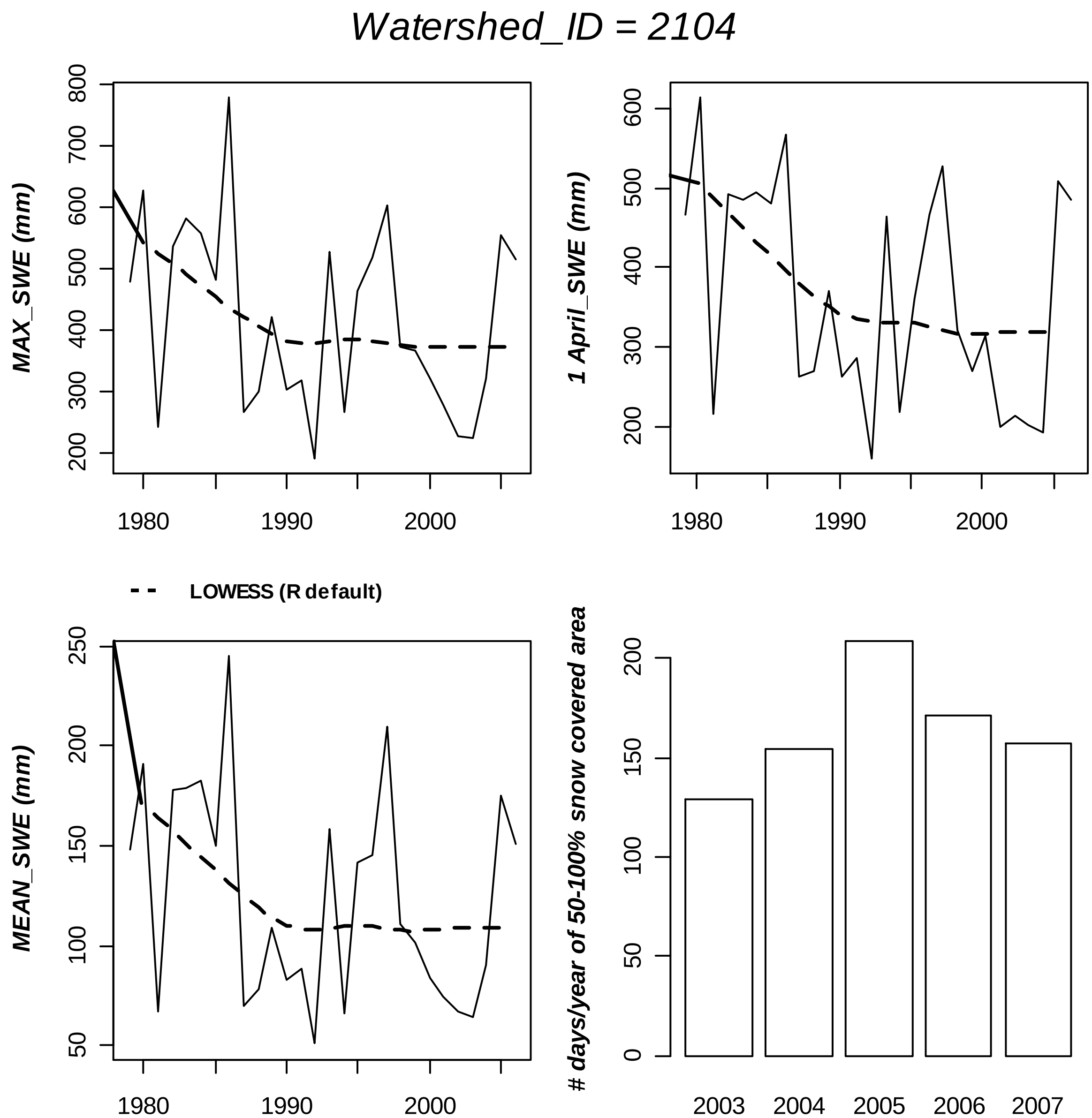

Figure 6.6. *Snowfall analyses for Duchesne River near Tabiona watershed (watershed_ID = 2104). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

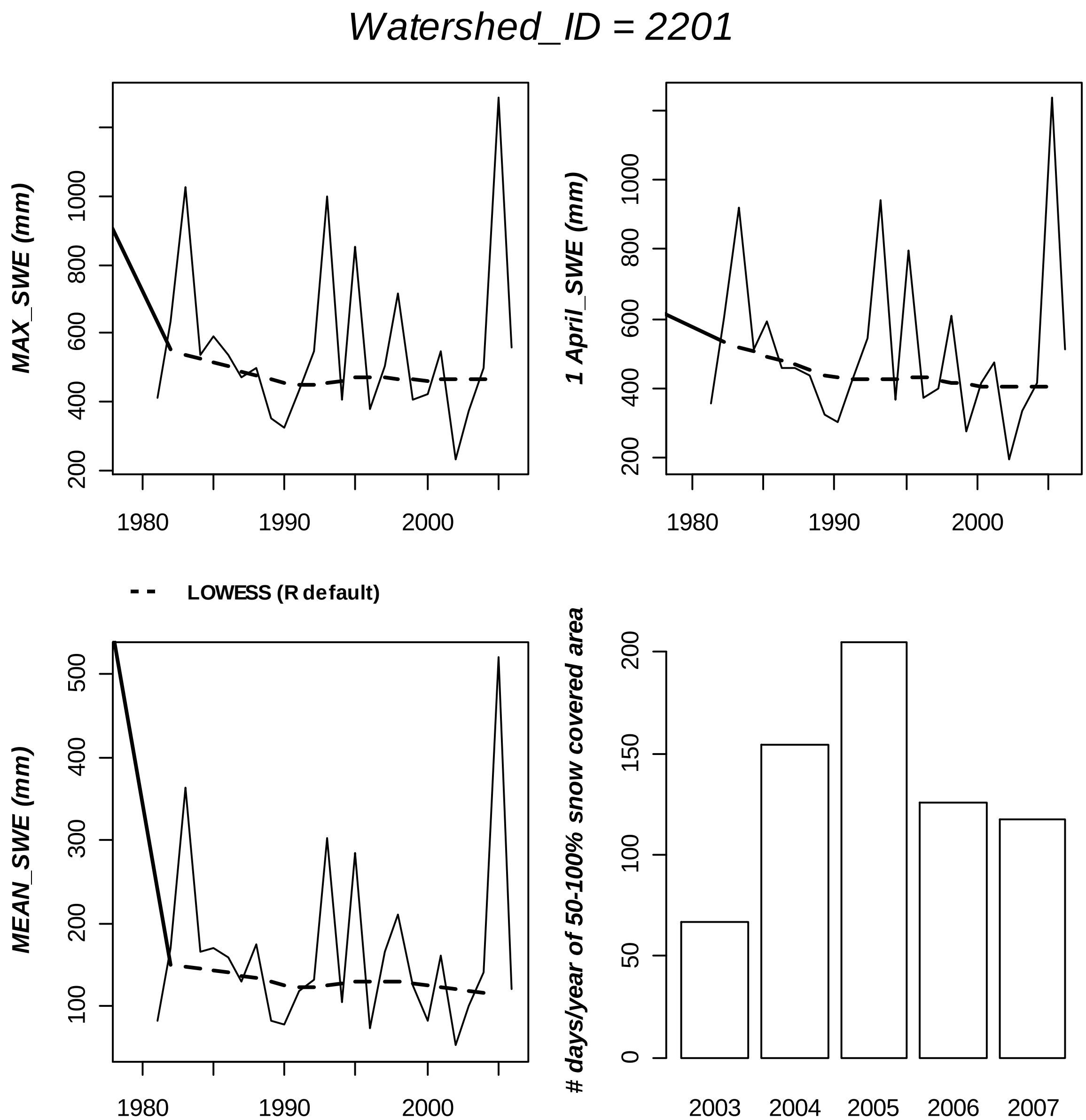

Figure 6.7. *Snowfall analyses for Sevier River at Hatch watershed (watershed_ID = 2201). The analyses shown above based upon water year give the maximum, the April 1st and the mean snow water equivalent. The time span for snow water equivalent products is 1979-2006. The lower right panel gives the number of days which have greater than 50% snow covered area per year.*

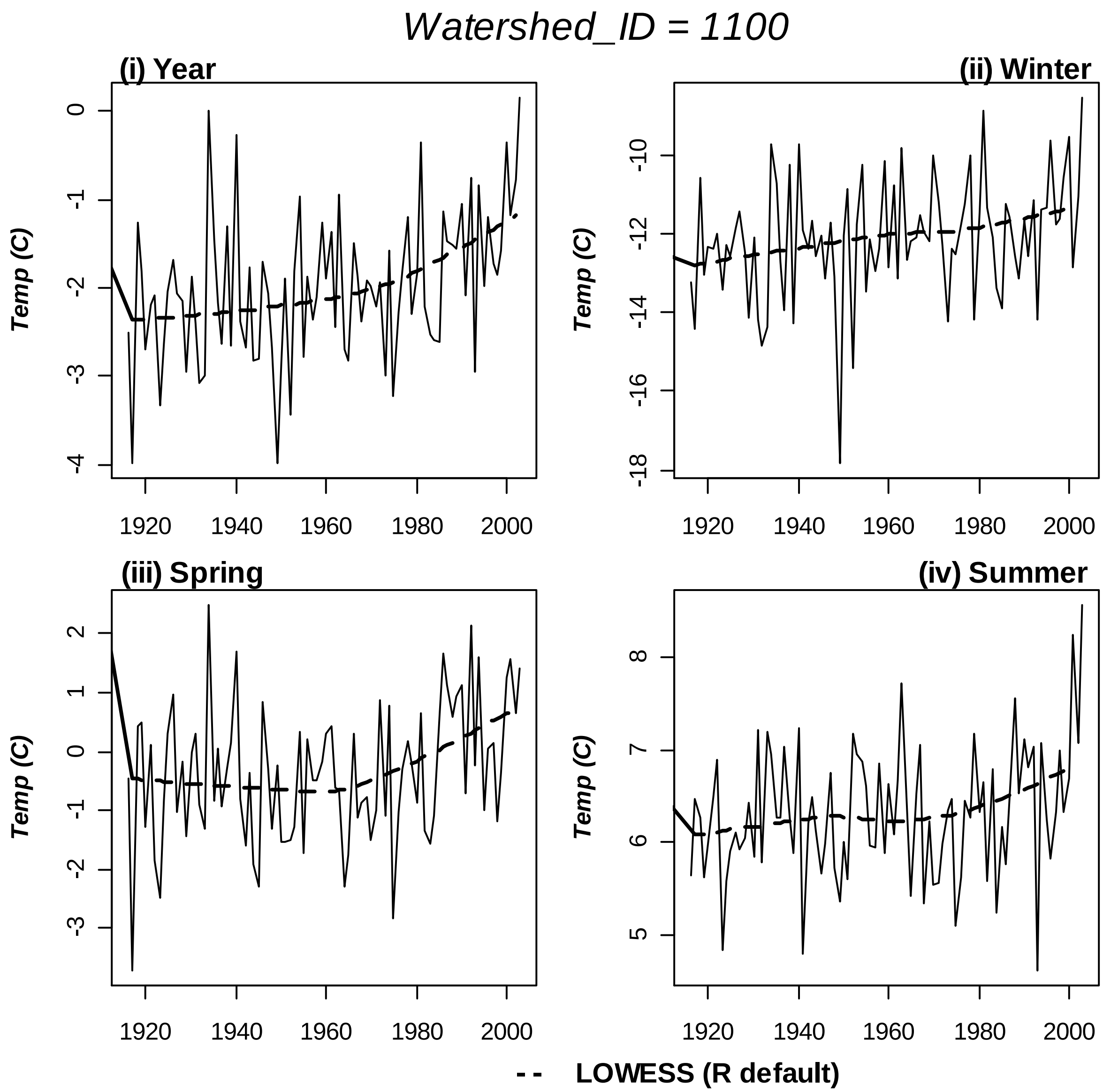

Figure 7.1. Temperature analyses for Bear River near Utah-Wyoming state line watershed (watershed_ID = 1100). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

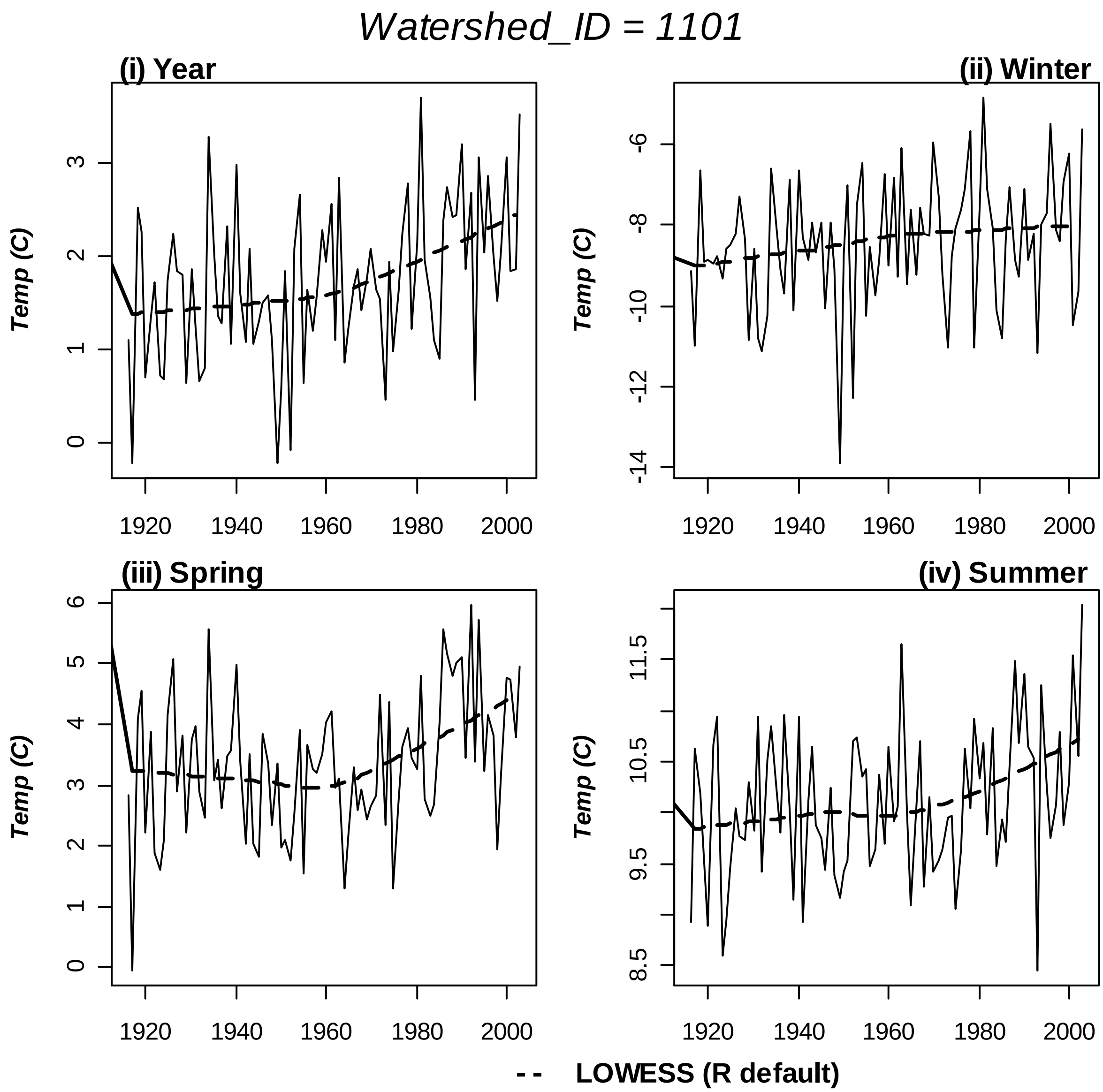

Figure 7.2. Temperature analyses for Bear River near Randolph watershed (watershed_ID = 1101). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

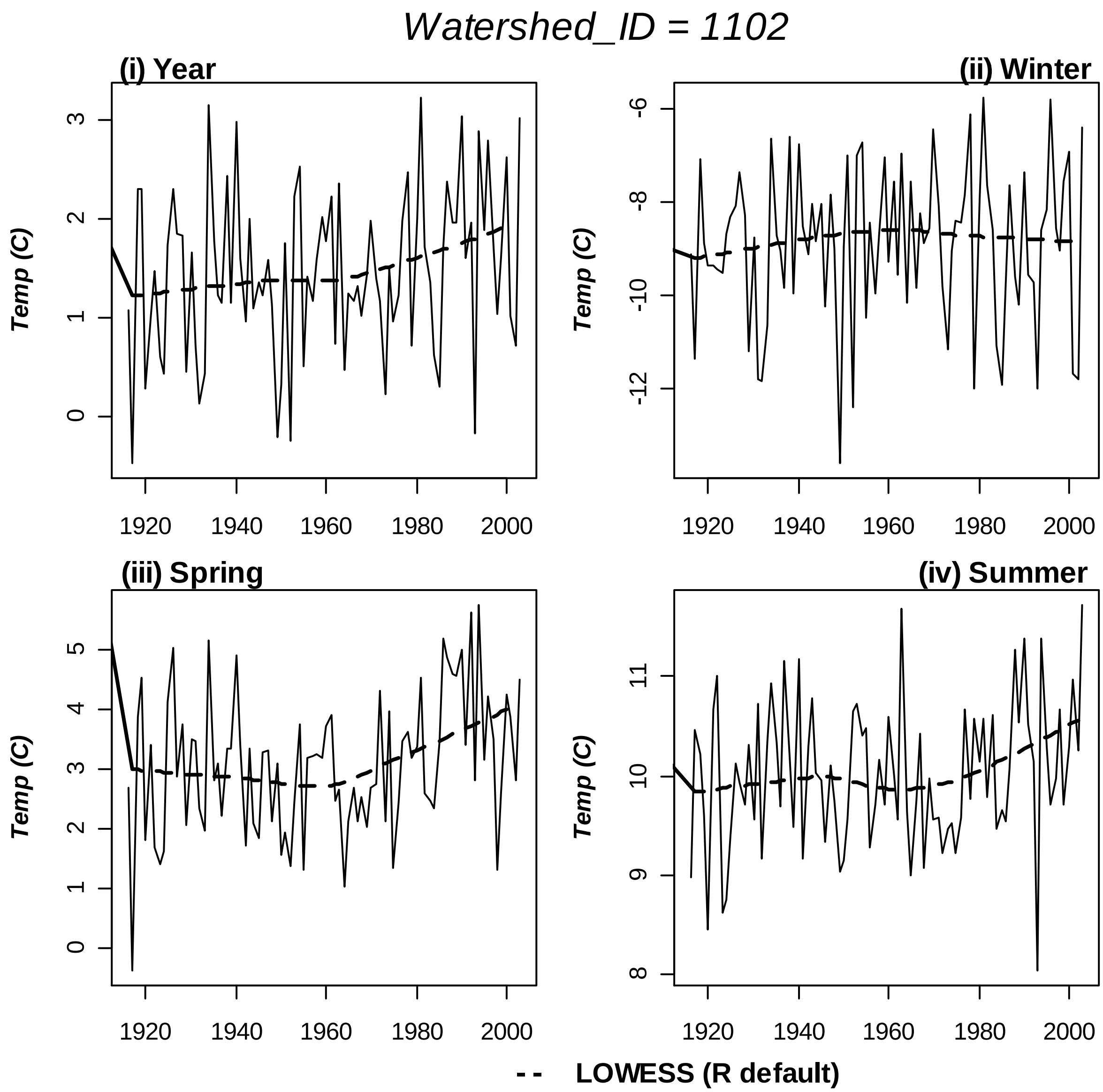

Figure 7.3. Temperature analyses for Big Creek near Randolph watershed (watershed_ID = 1102). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

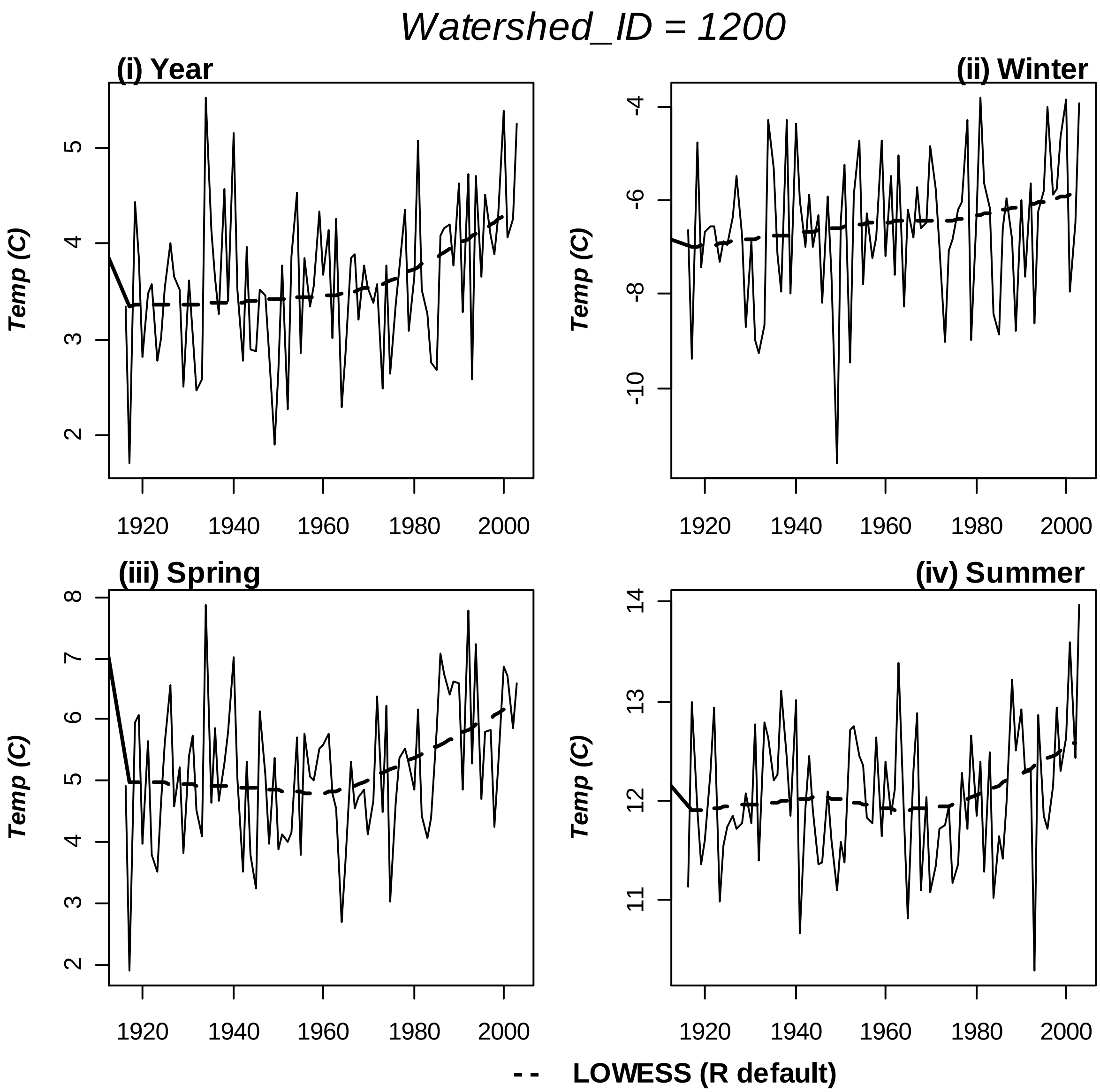

Figure 7.4. Temperature analyses for Weber River at Gateway watershed (watershed_ID = 1200). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

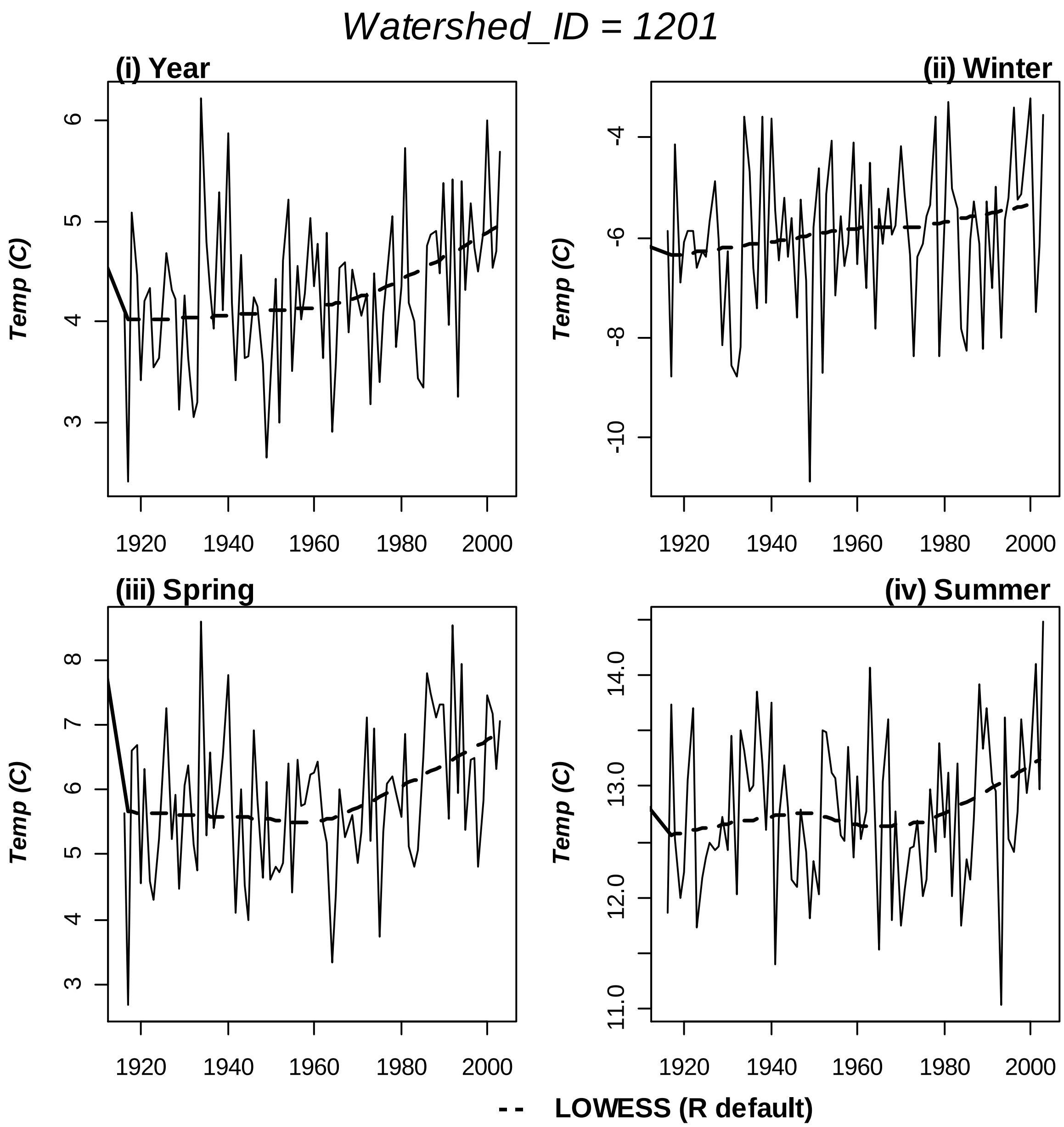

Figure 7.5. Temperature analyses for Weber River near Plain City watershed (watershed_ID = 1201). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

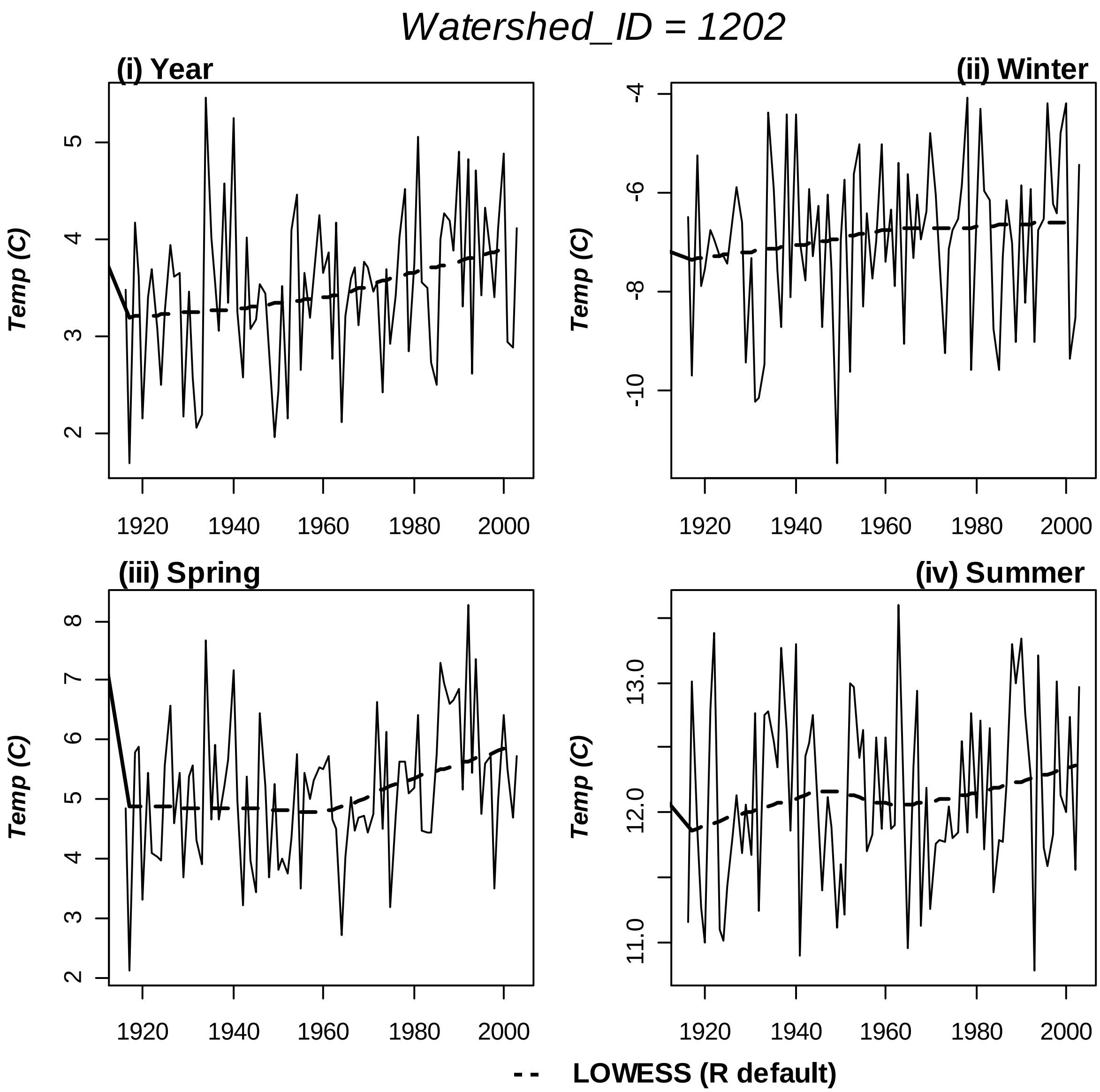

Figure 7.6. Temperature analyses for South Fork Ogden River near Huntsville watershed (watershed_ID = 1202). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

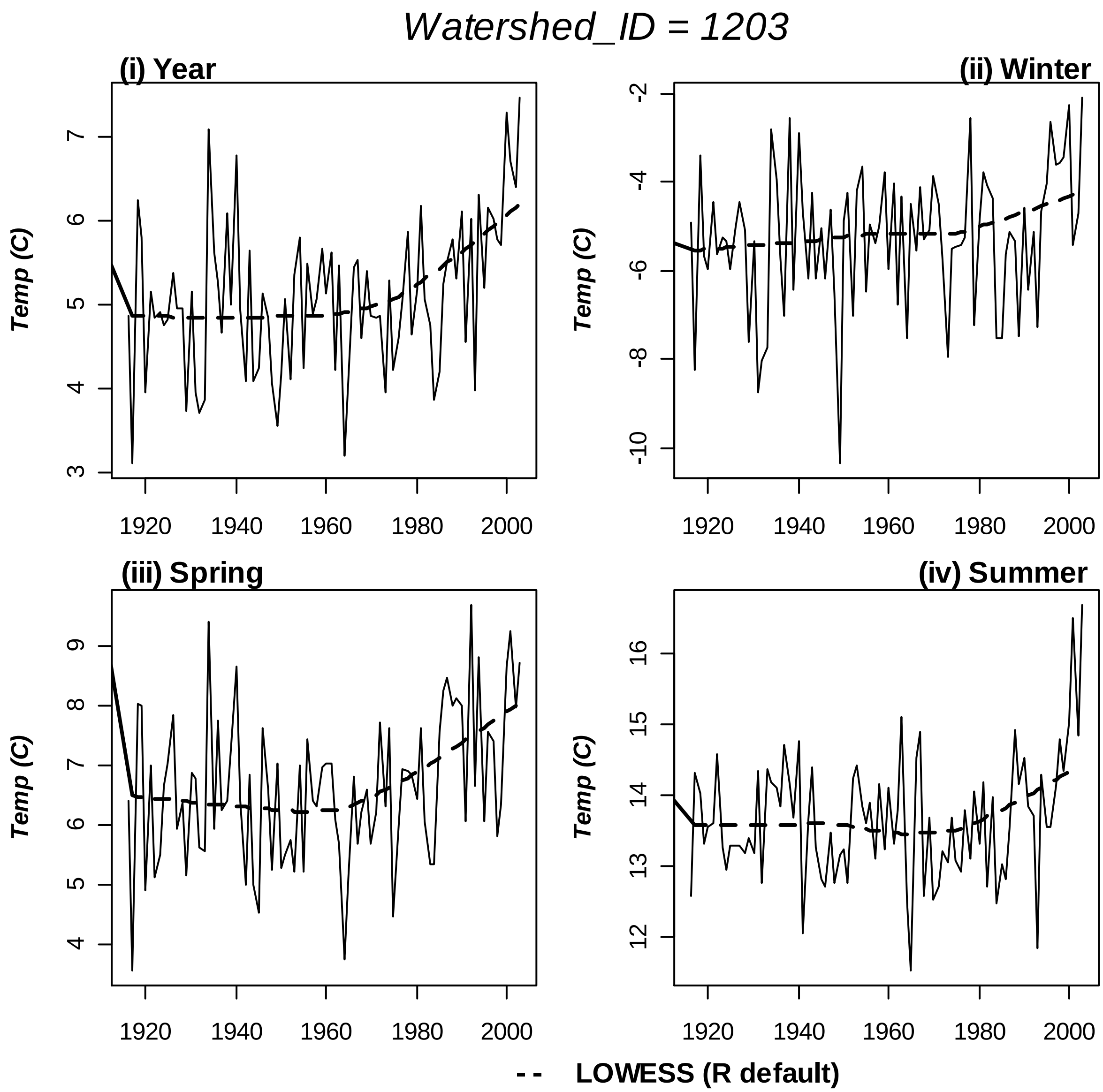

Figure 7.7. Temperature analyses for Centerville Creek near Centerville watershed (watershed_ID = 1203). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

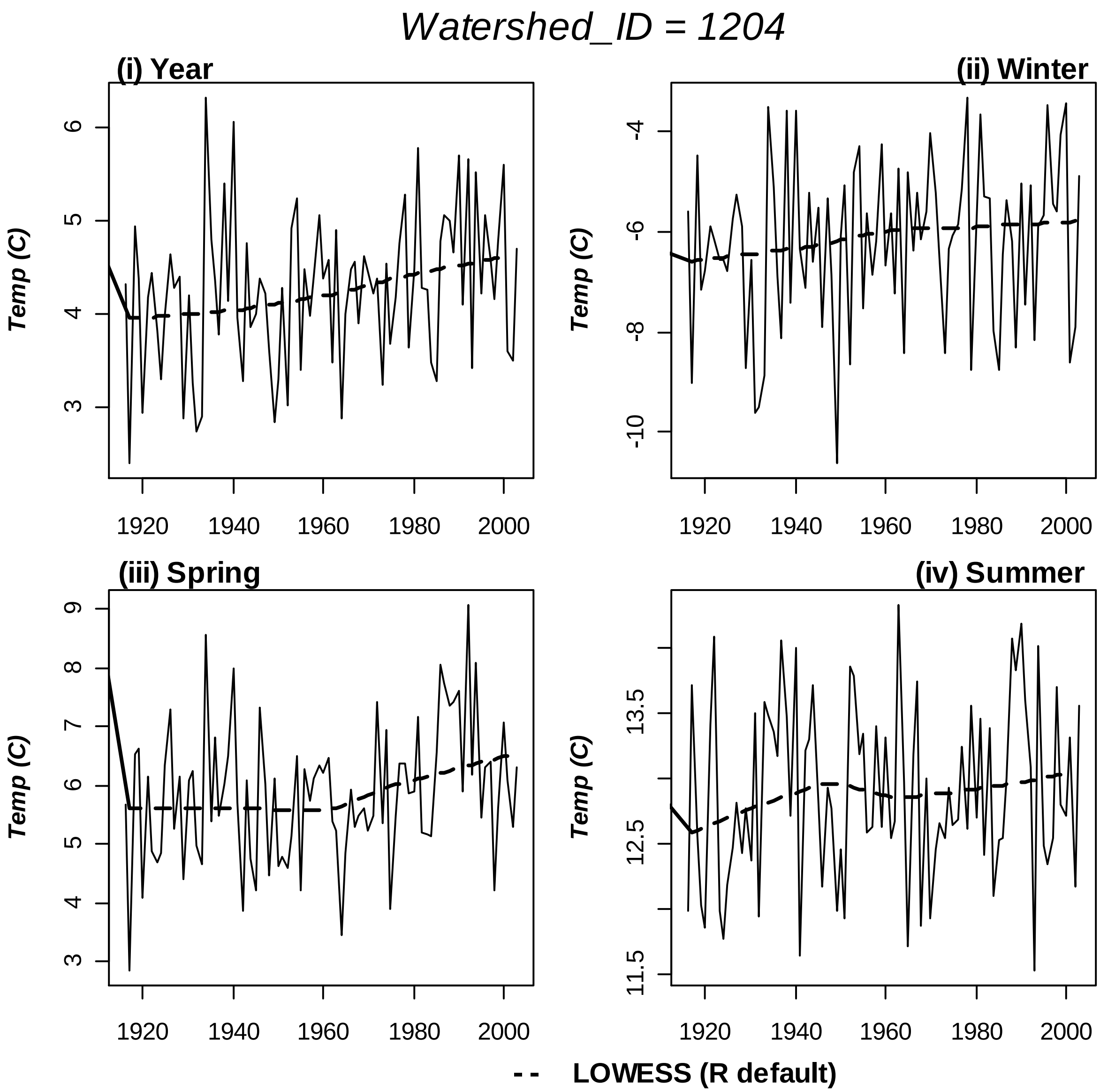

Figure 7.8. Temperature analyses for Ogden River below Pineview near Huntsville watershed (watershed_ID = 1204). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

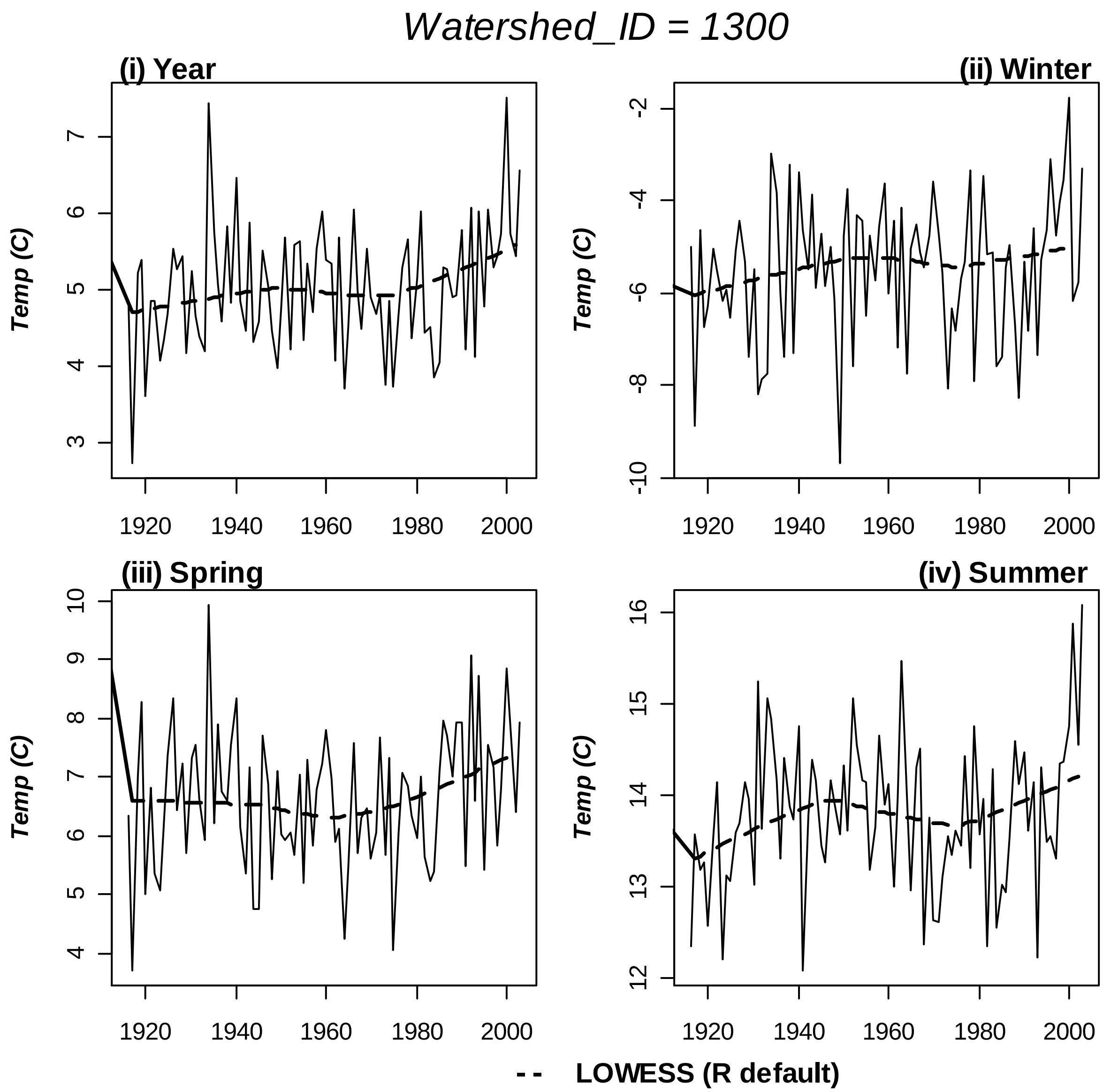

Figure 7.9. Temperature analyses for Salt Creek at Nephi watershed (watershed_ID = 1300). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

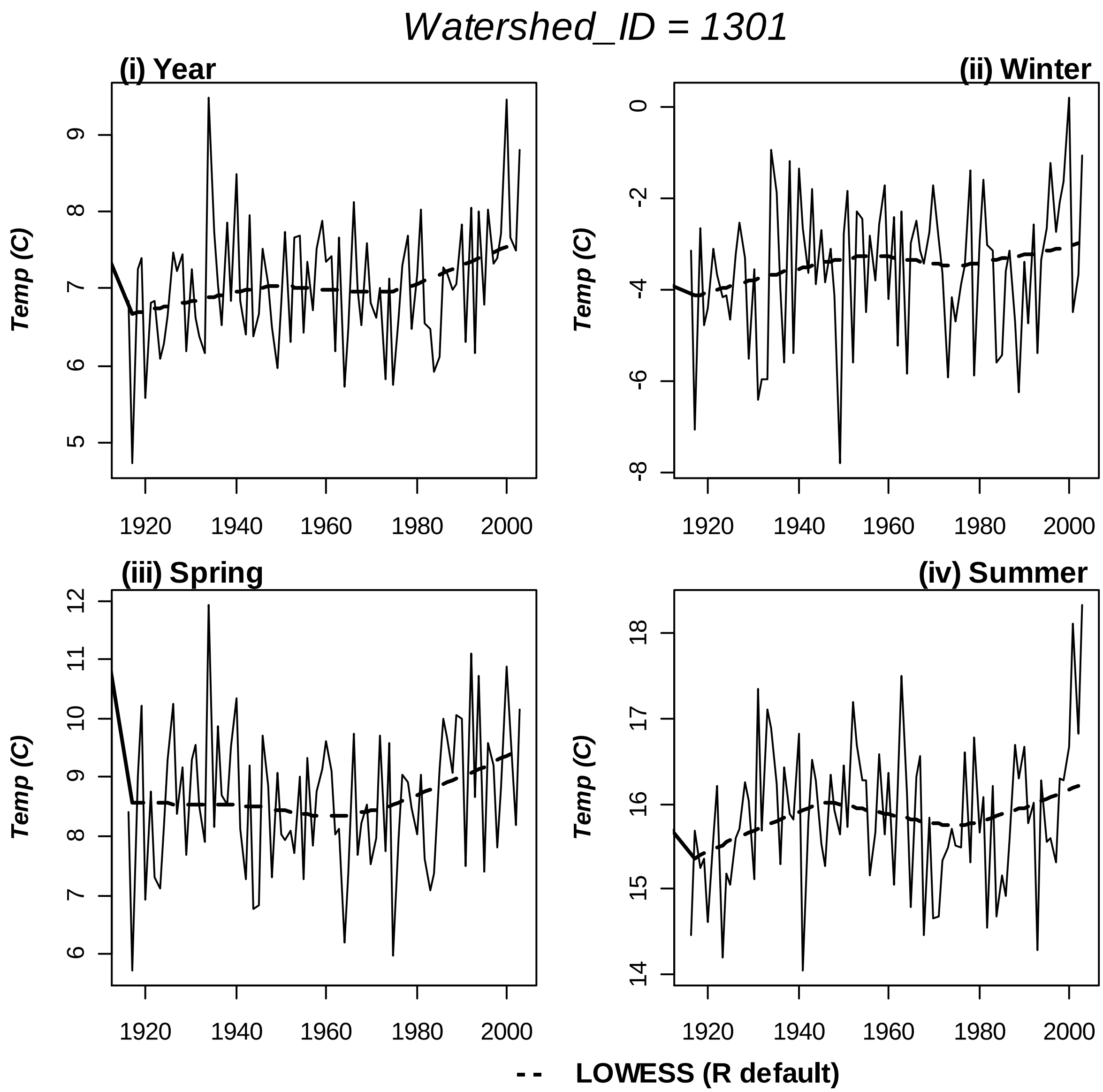

Figure 7.10. Temperature analyses for Currant Creek near Mona watershed (watershed_ID = 1301). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

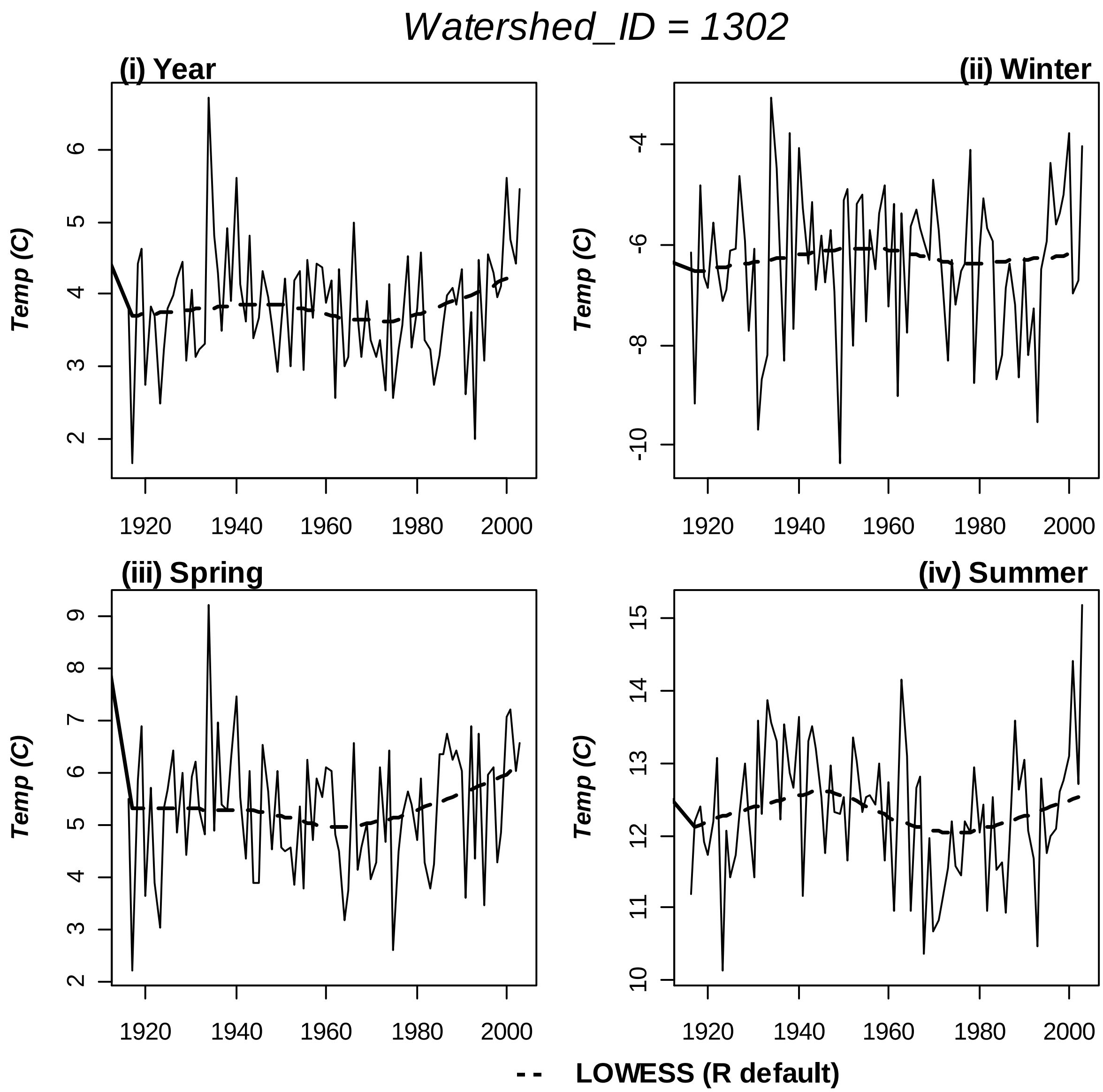

Figure 7.11. Temperature analyses for West Canyon Creek near Cedar Fort watershed (watershed_ID = 1302). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

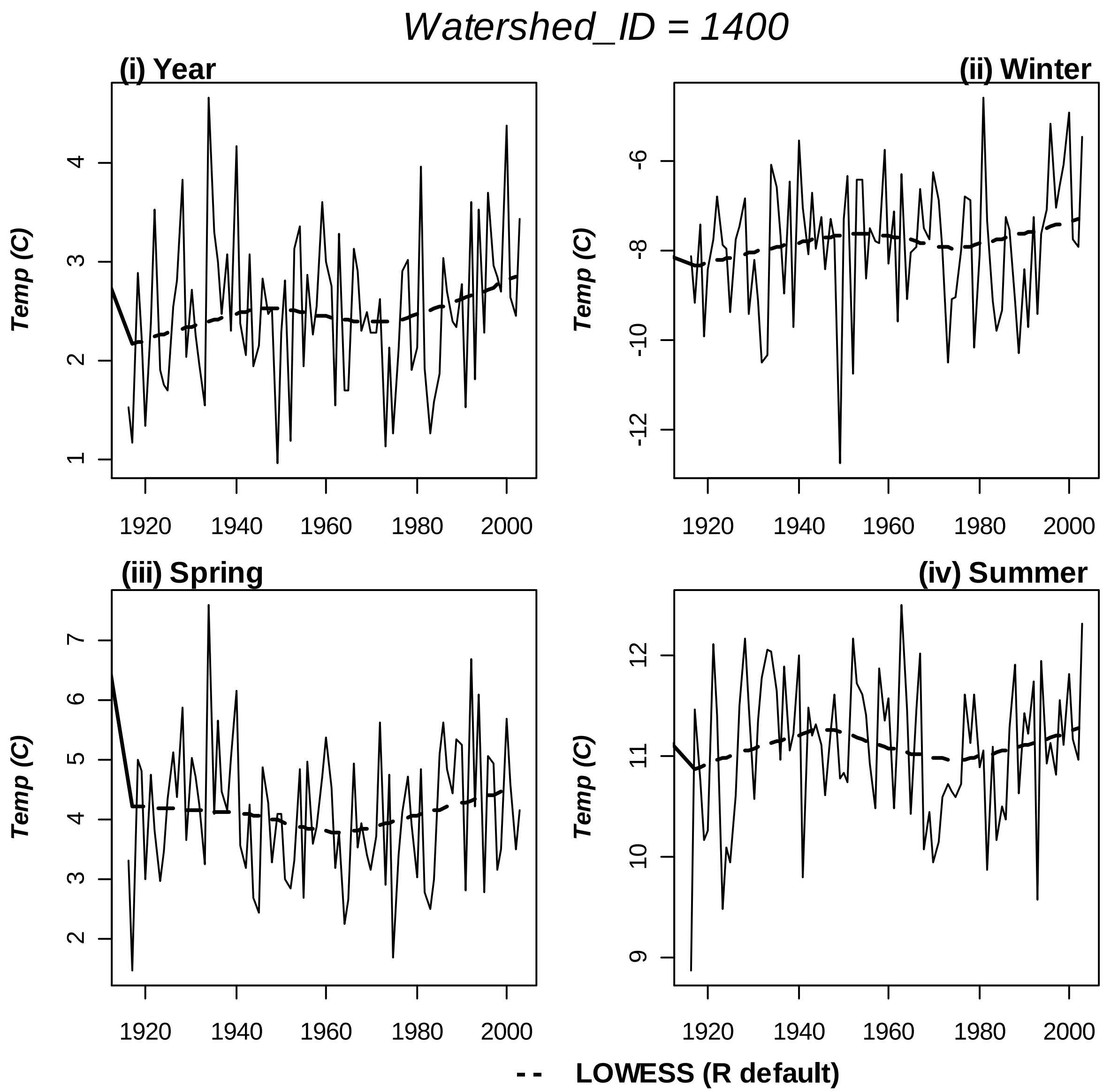

Figure 7.12. Temperature analyses for Fish Creek near Scofield watershed (watershed_ID = 1400). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

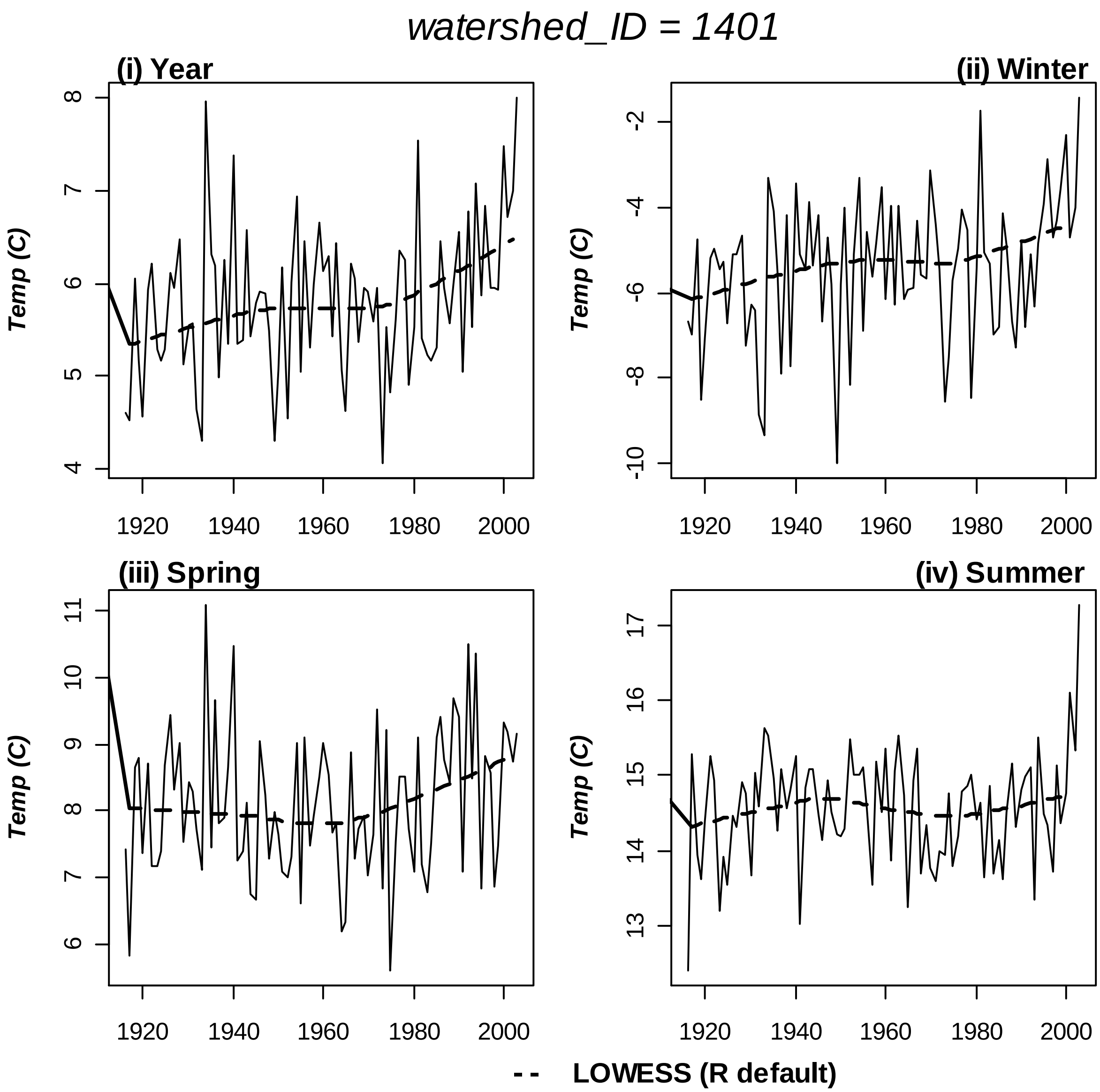

Figure 7.13. Temperature analyses for Price River at Woodside watershed (watershed_ID = 1401). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

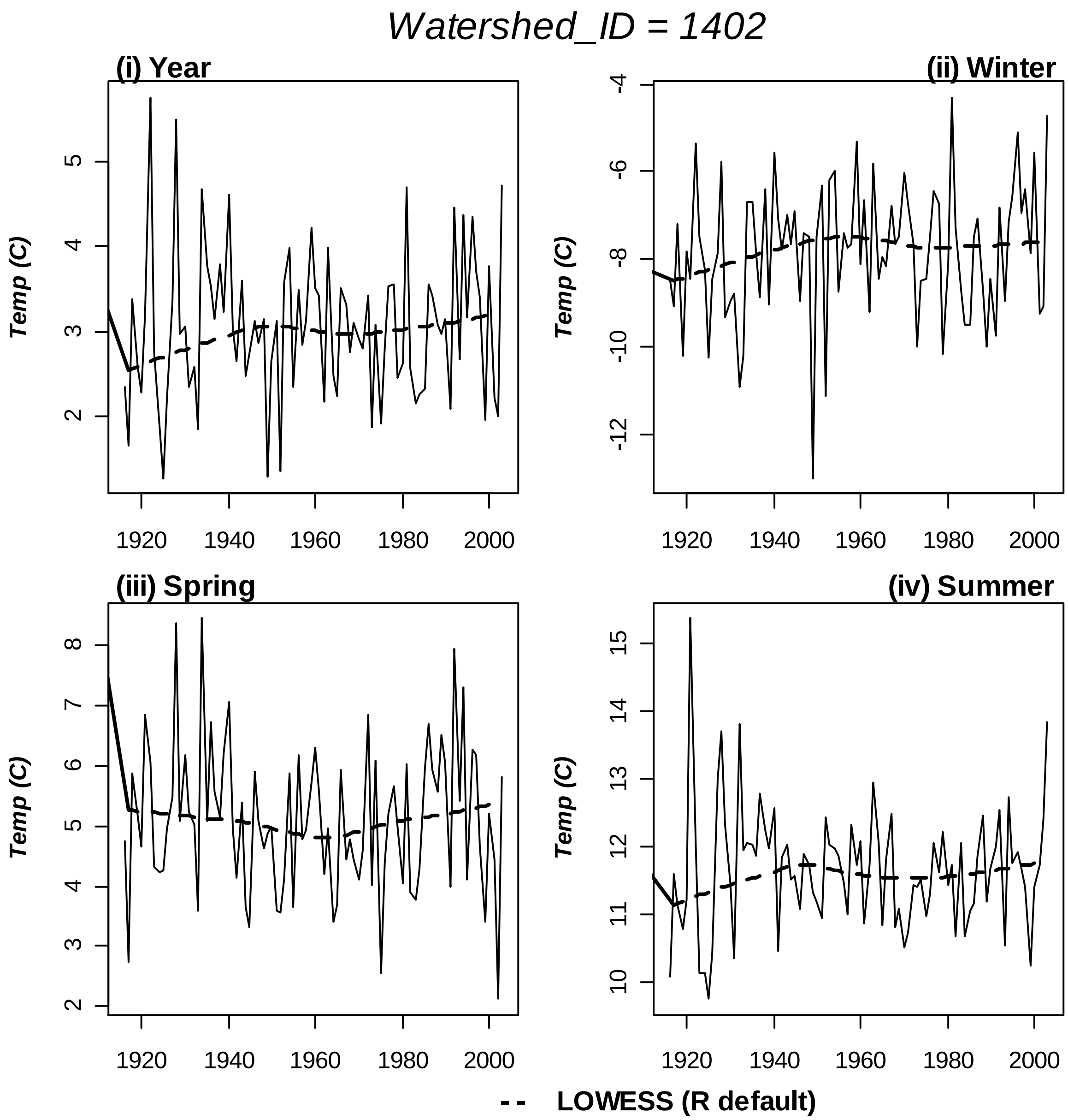

Figure 7.14. Temperature analyses for White River below Tabbyune Creek near Soldier Summit watershed (watershed_ID = 1402). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

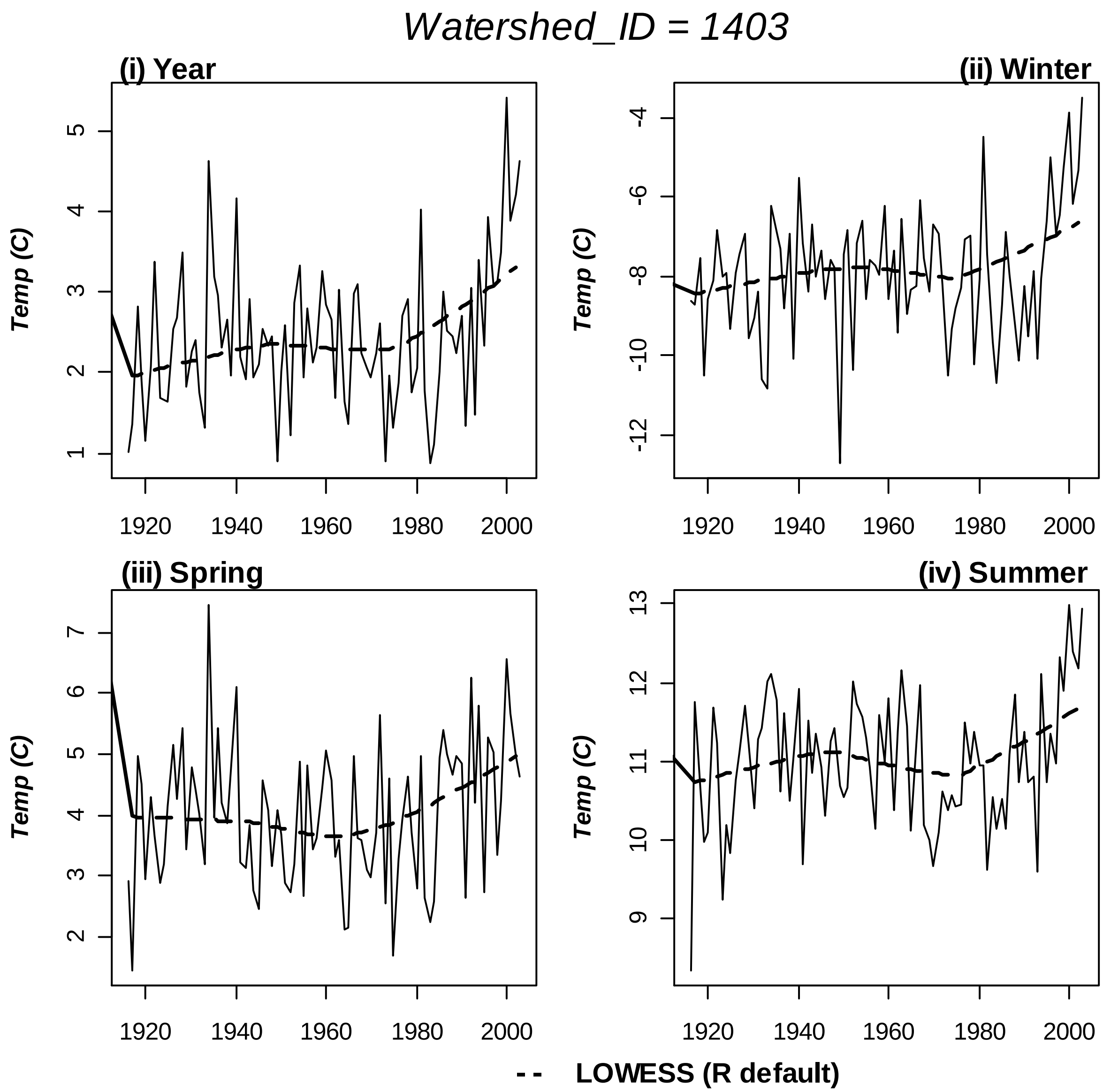

Figure 7.15. Temperature analyses for Mud Creek below Winter Quarters Canyon at Scofield watershed (watershed_ID = 1403). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

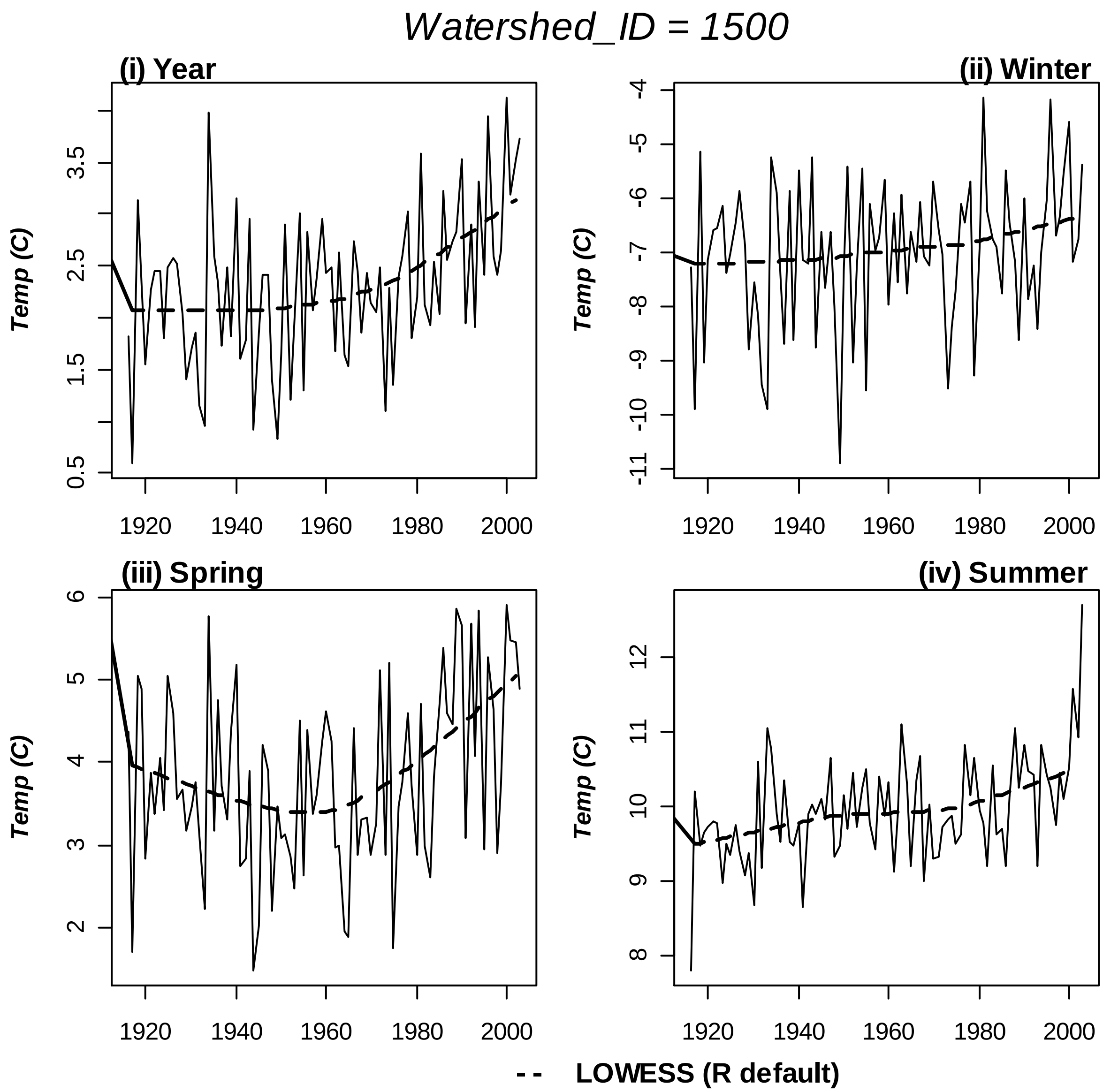

Figure 7.16. Temperature analyses for Fremont River near Bicknell watershed (watershed_ID = 1500). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

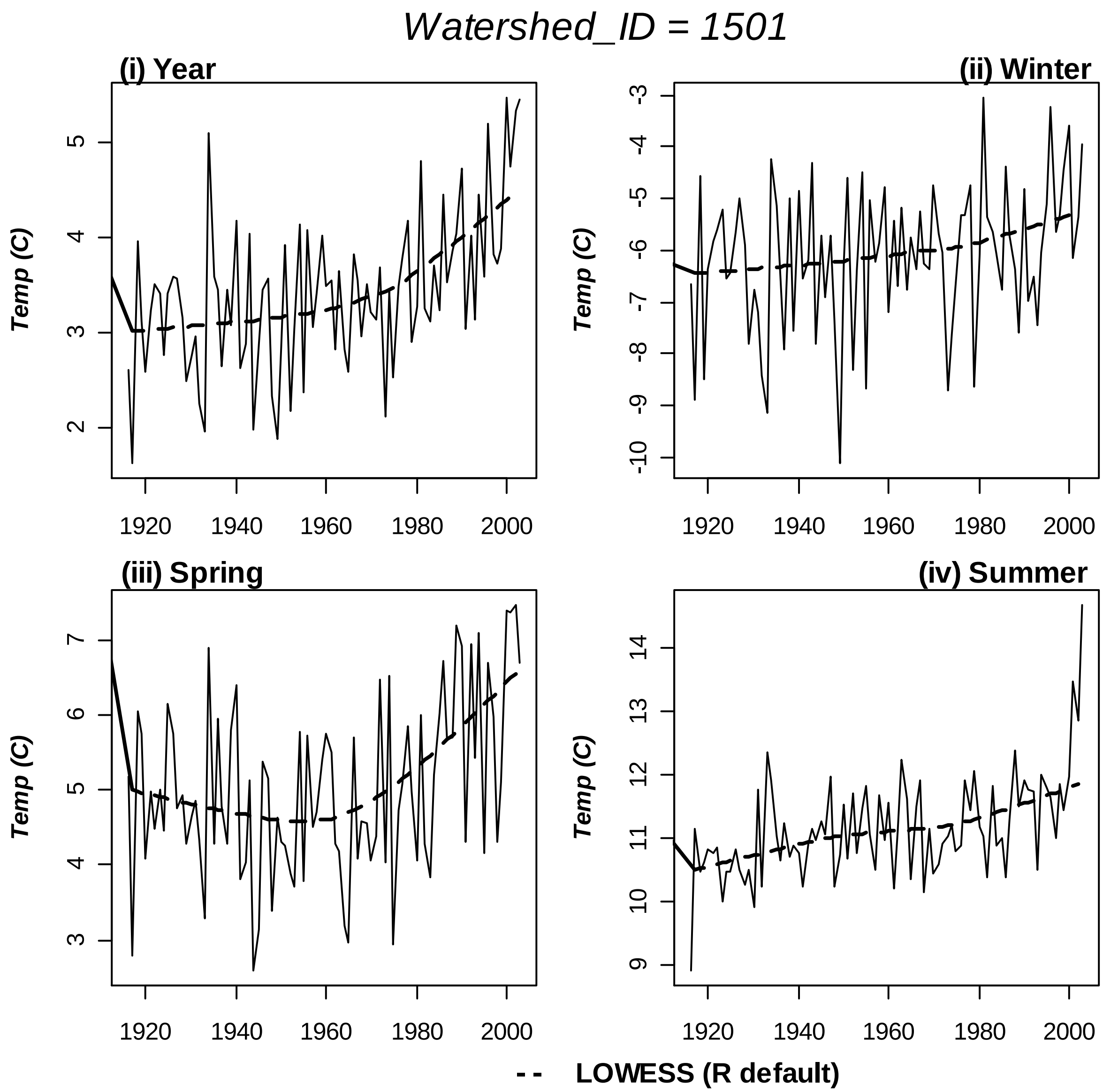

Figure 7.17. Temperature analyses for Fremont River near Caineville watershed (watershed_ID = 1501). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

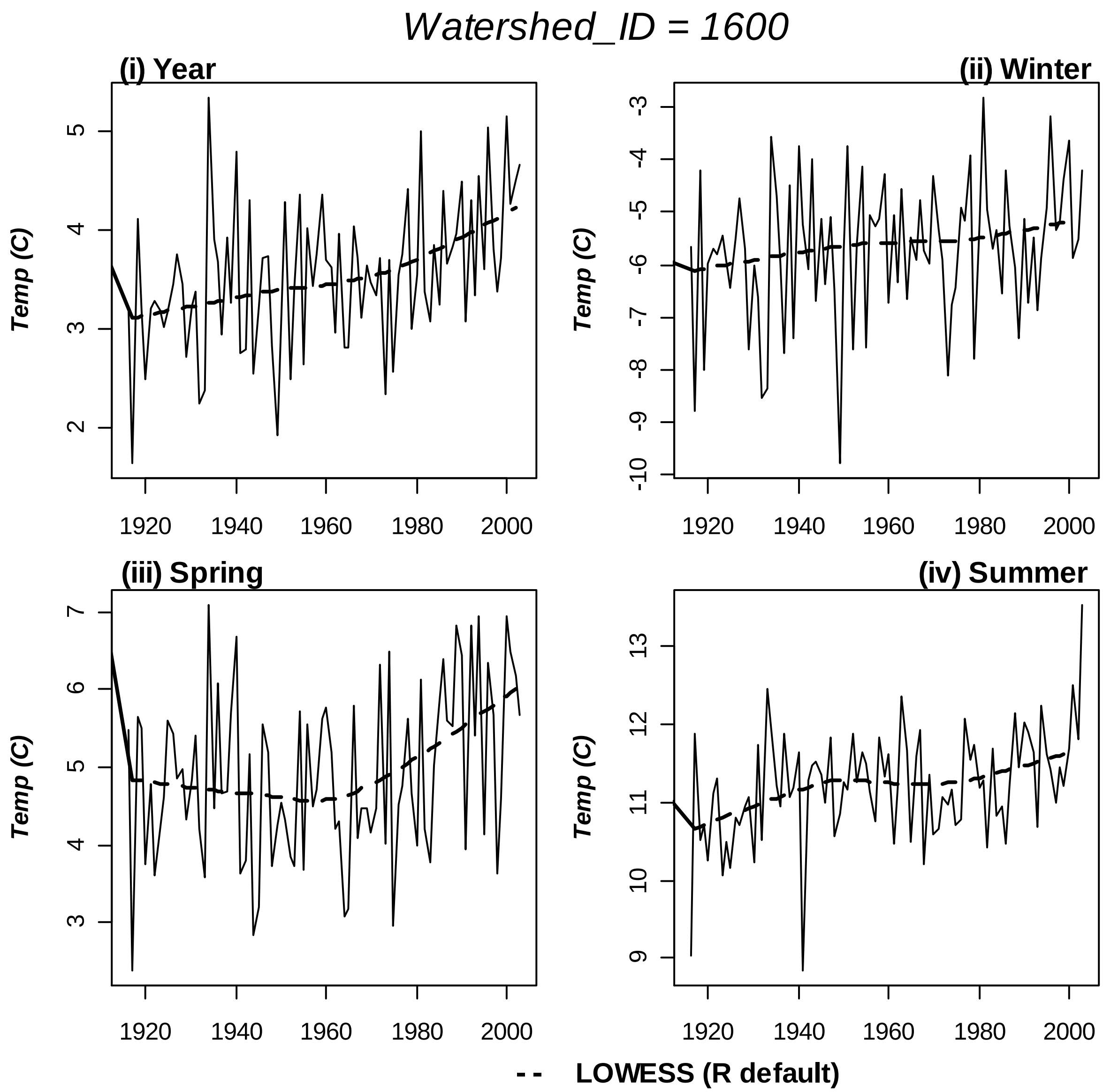

Figure 7.18. Temperature analyses for East Fork Sevier River near Kingston watershed (watershed_ID = 1600). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

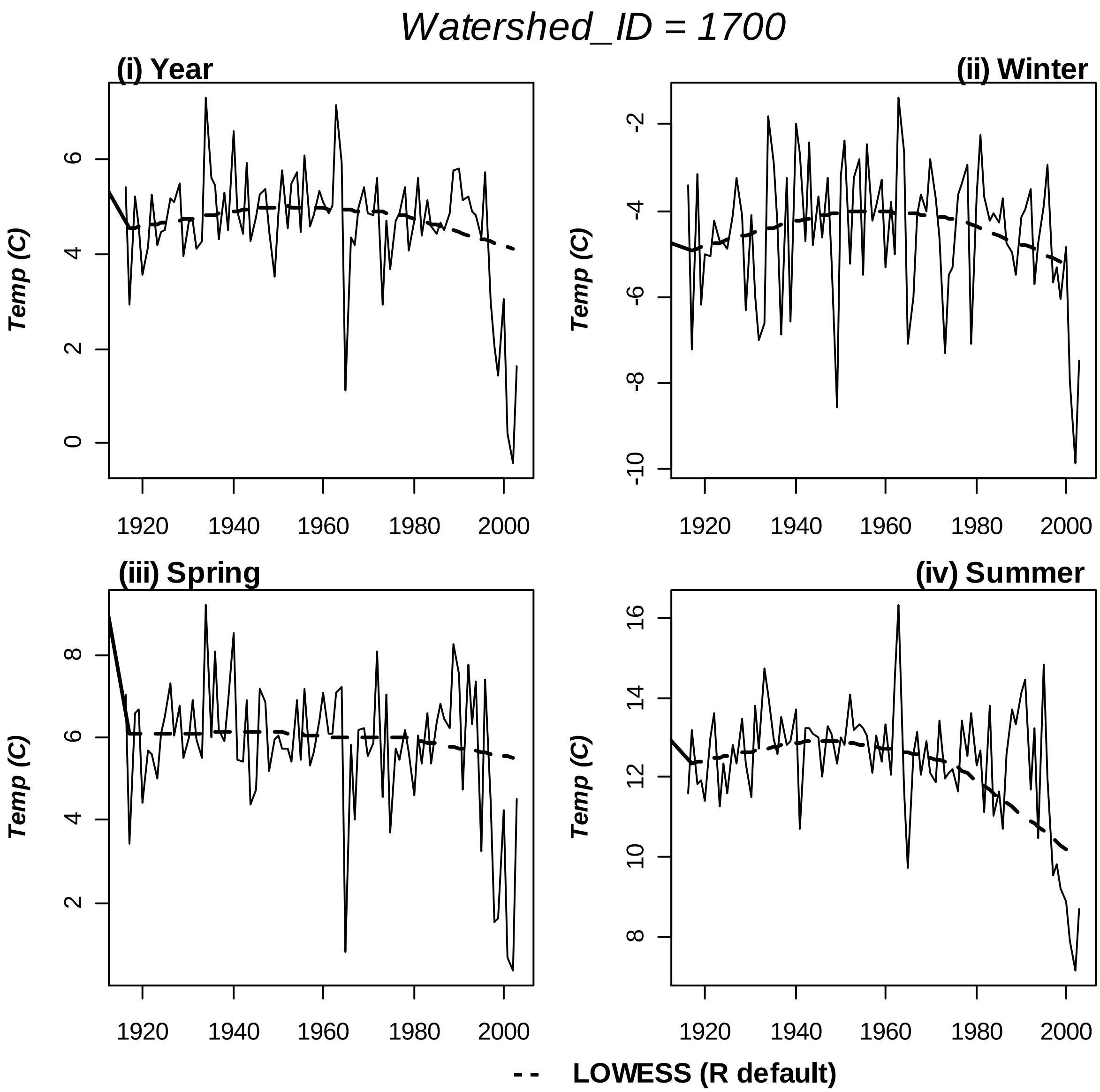

Figure 7.19. Temperature analyses for Coal Creek near Cedar City watershed (watershed_ID = 1700). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

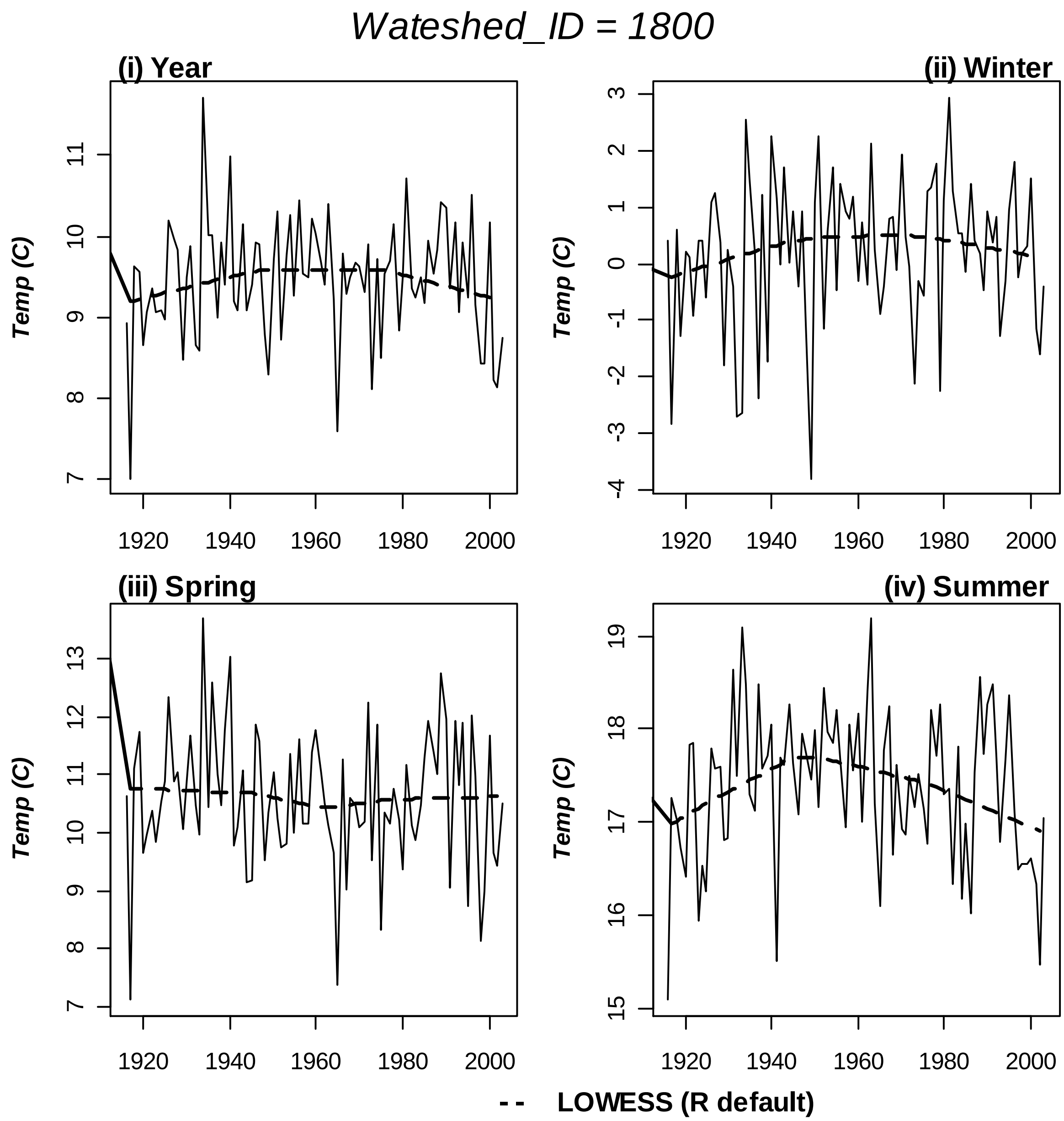

Figure 7.20. Temperature analyses for Virgin River at Virgin watershed (watershed_ID = 1800). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

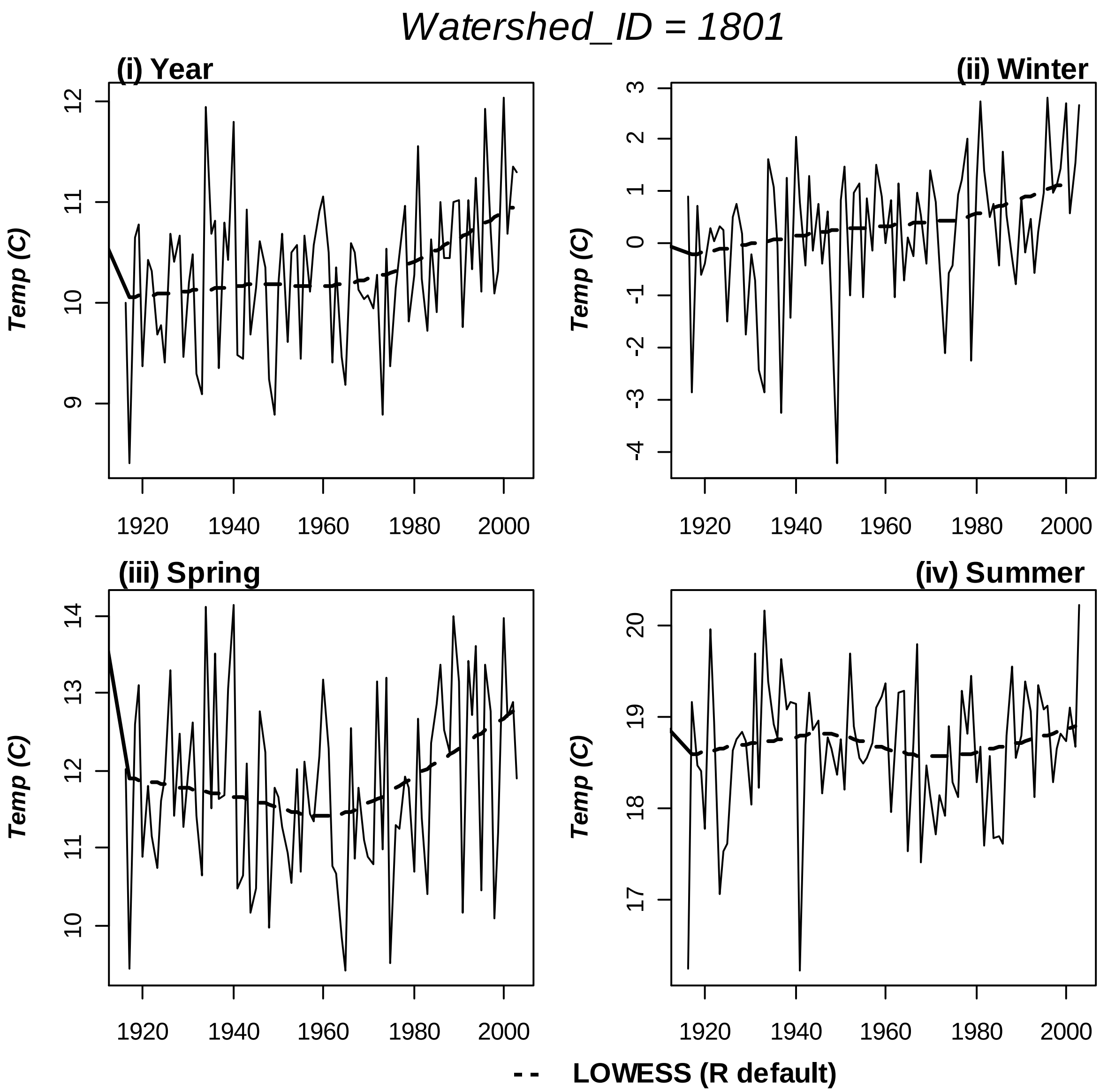

Figure 7.21. Temperature analyses for Santa Clara River at Gunlock watershed (watershed_ID = 1801). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

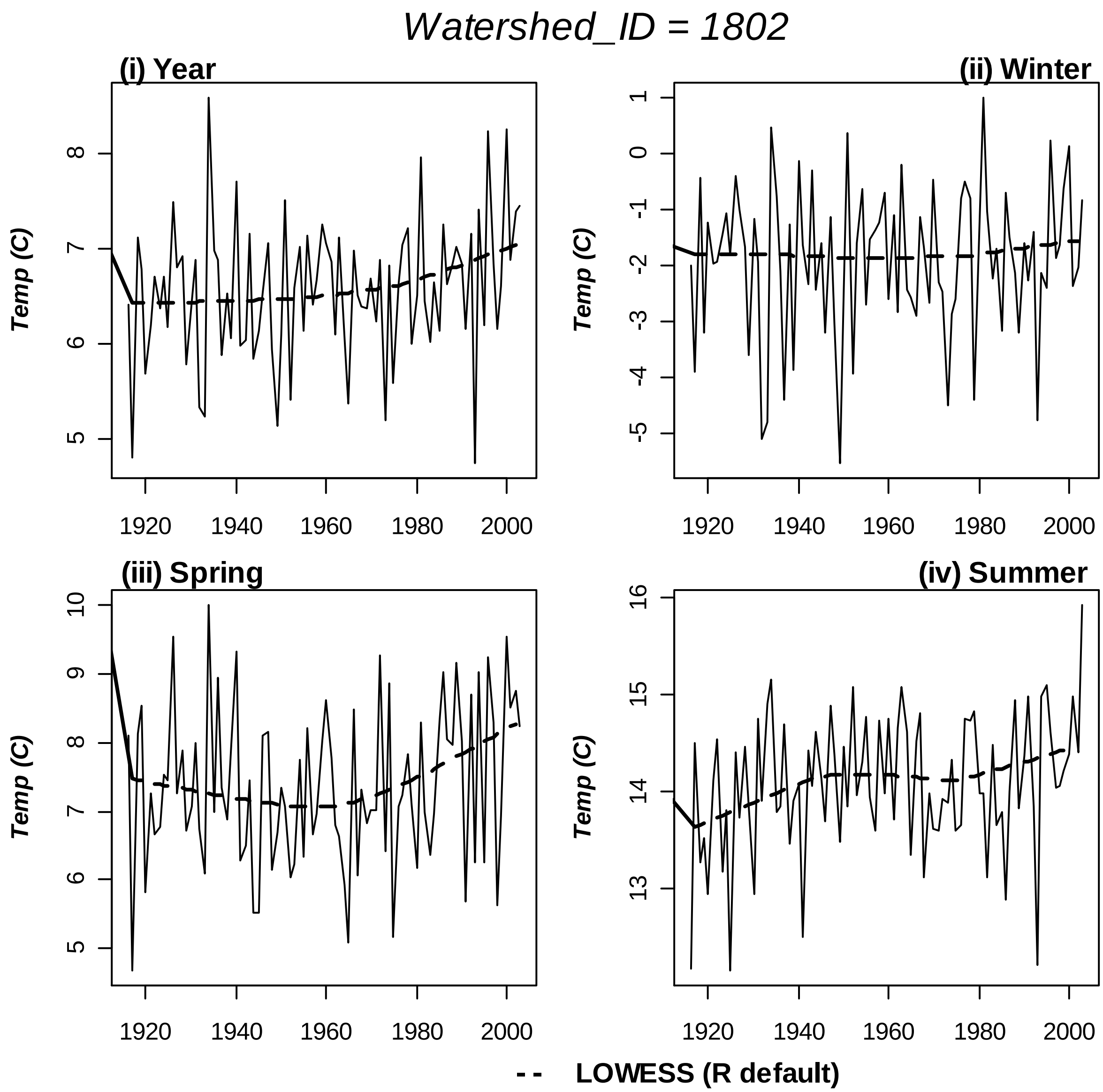

Figure 7.22. Temperature analyses for East Fork Virgin River near Glendale watershed (watershed_ID = 1802). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

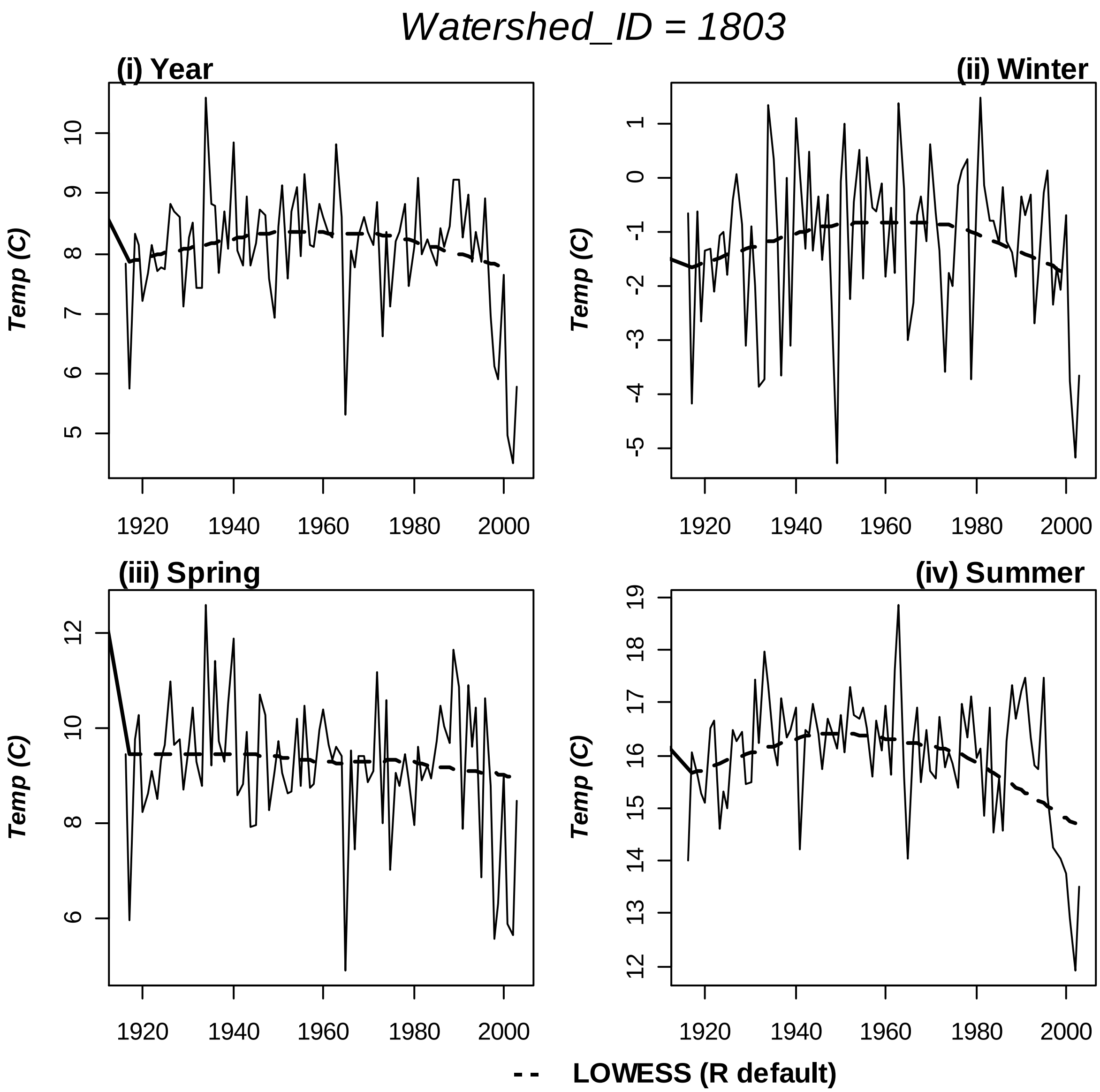

Figure 7.23. Temperature analyses for North Fork Virgin River near Springdale watershed (watershed_ID = 1803). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

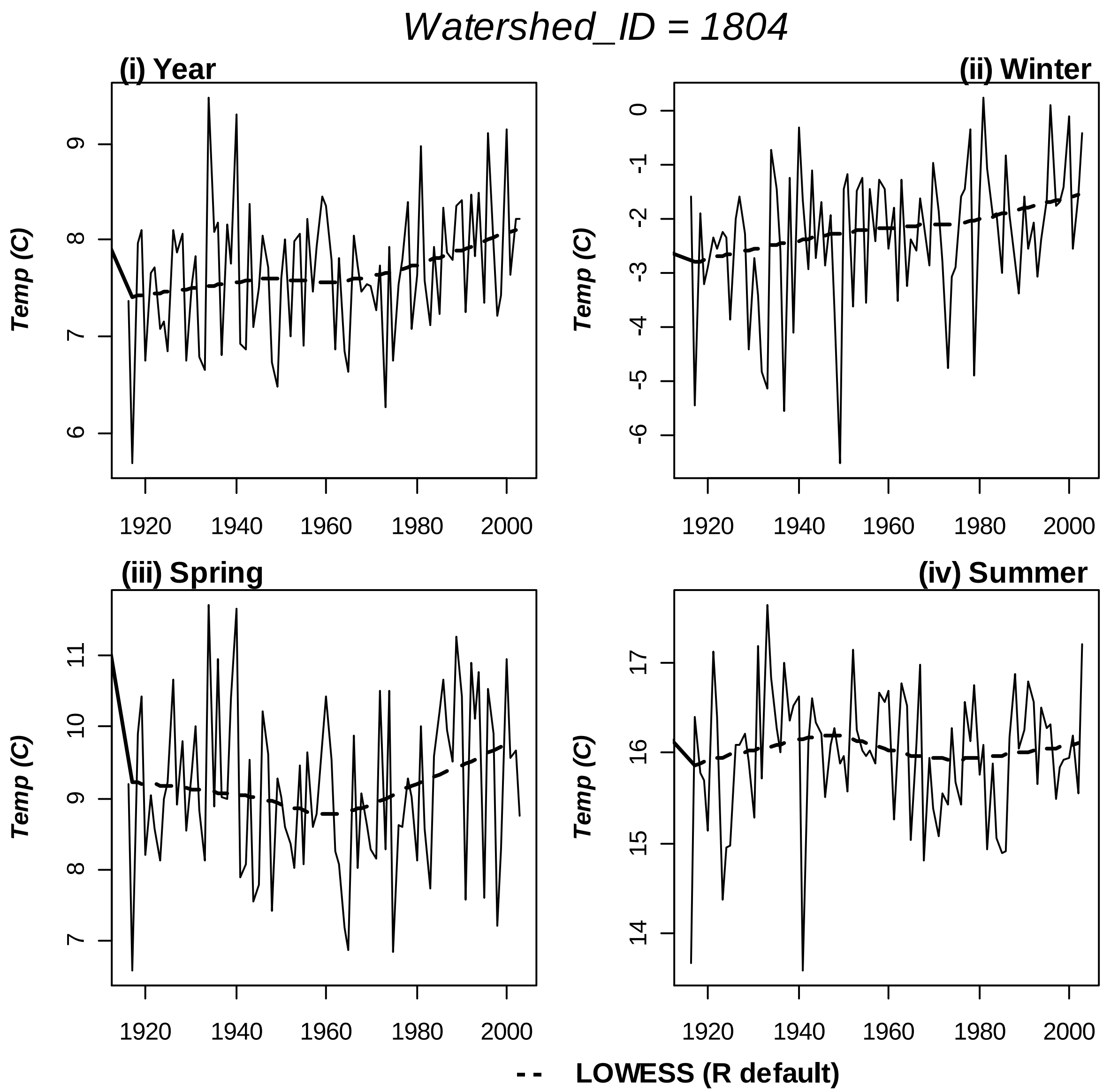

Figure 7.24. Temperature analyses for Santa Clara River above Baker near Central watershed (watershed_ID = 1804). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

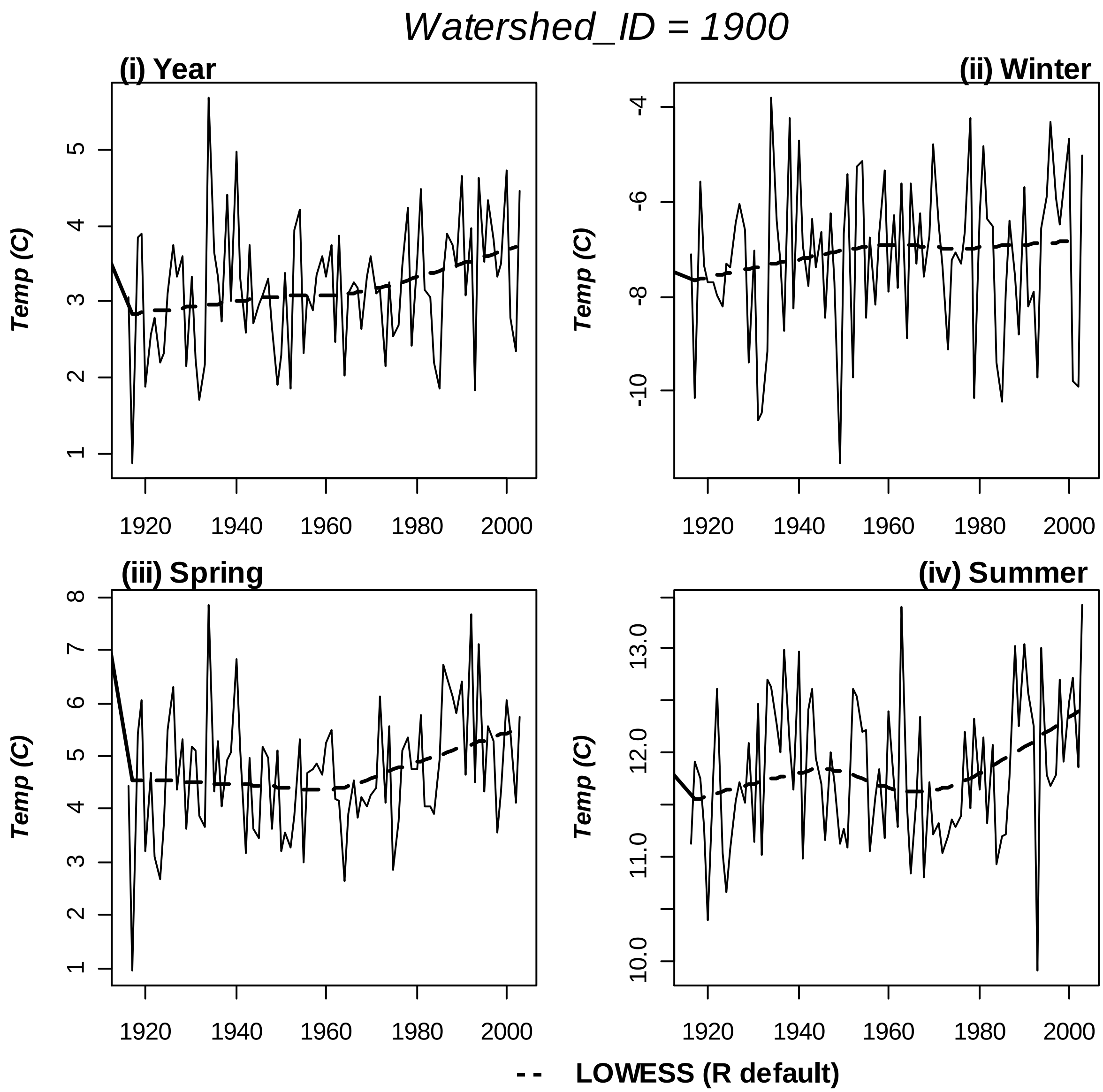

Figure 7.25. Temperature analyses for Blacksmith Fork near Hyrum watershed (watershed_ID = 1900). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

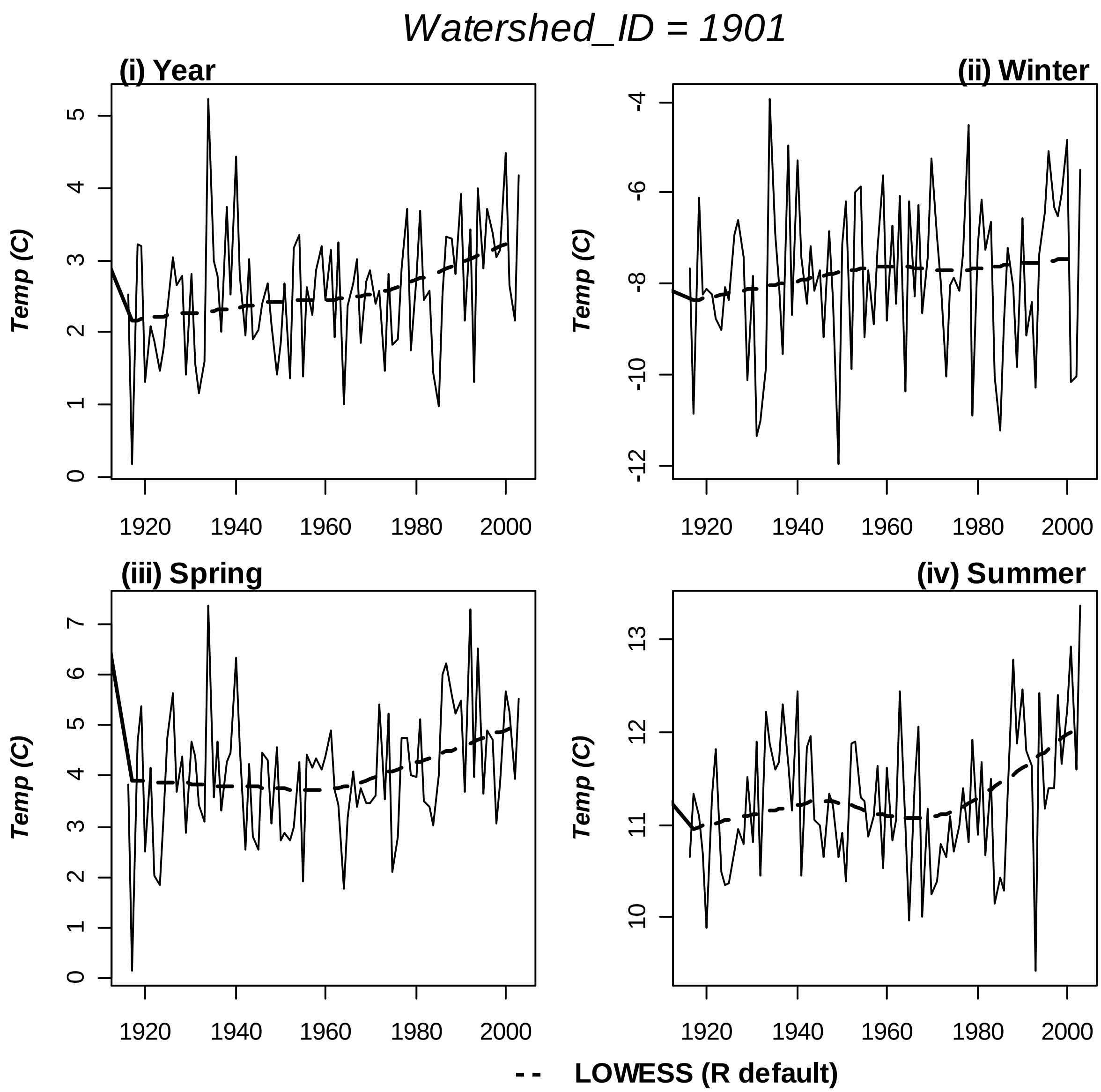

Figure 7.26. Temperature analyses for Logan River near Logan watershed (watershed_ID = 1901). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

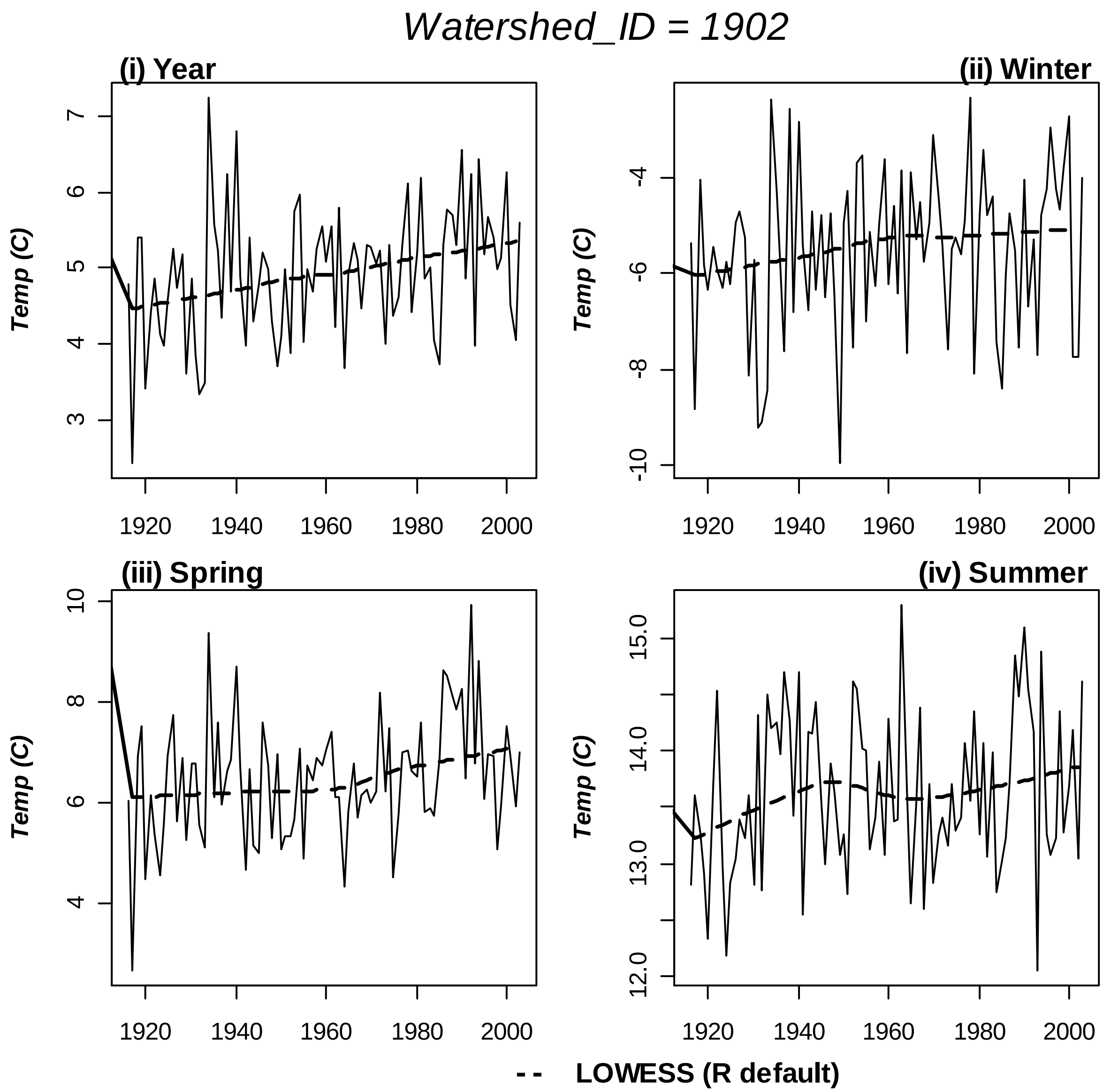

Figure 7.27. Temperature analyses for Little Bear River at Paradise watershed (watershed_ID = 1902). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

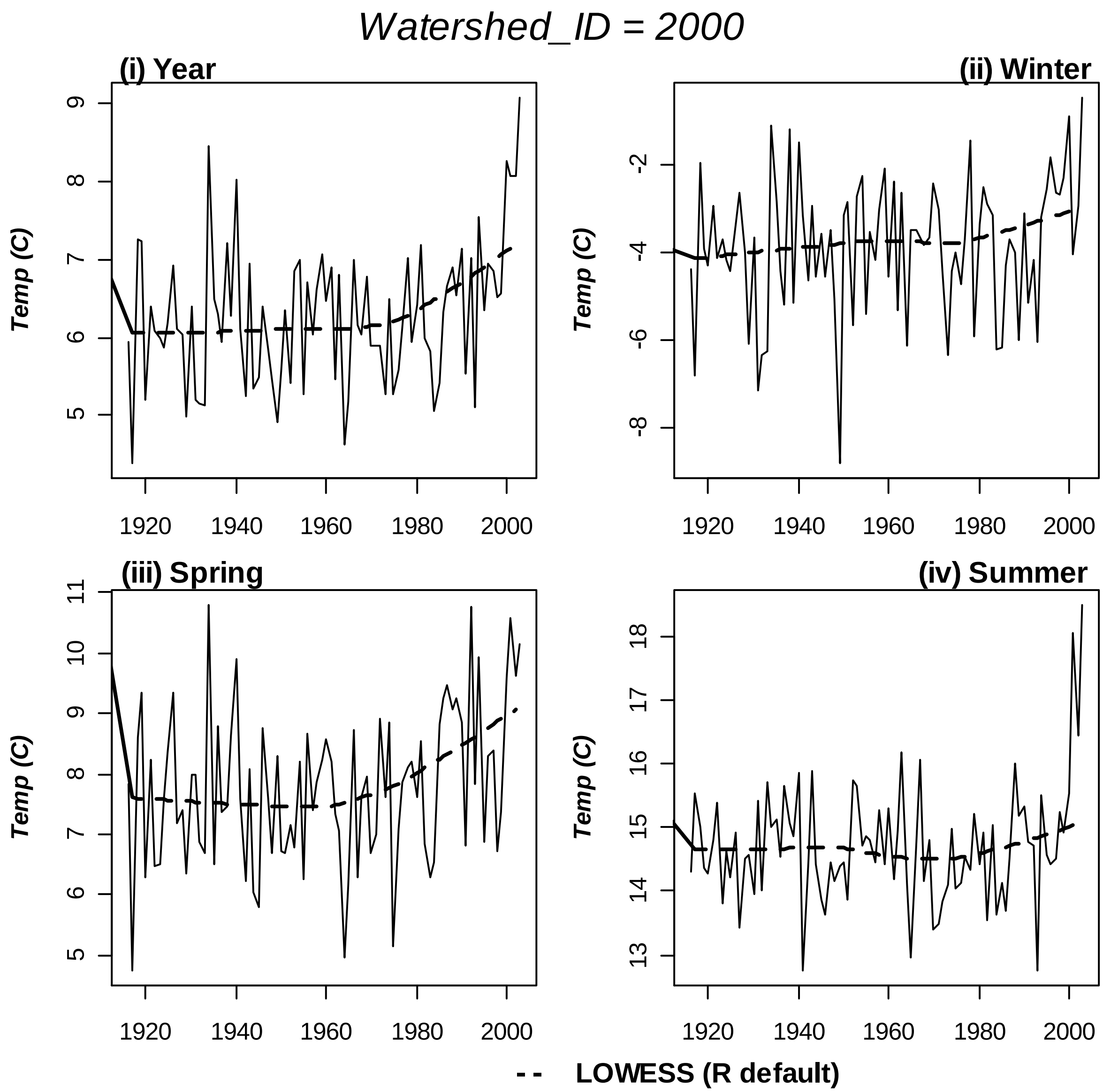

Figure 7.28. Temperature analyses for Red Butte Creek at Fort Douglas near Salt Lake City watershed (watershed_ID = 2000). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

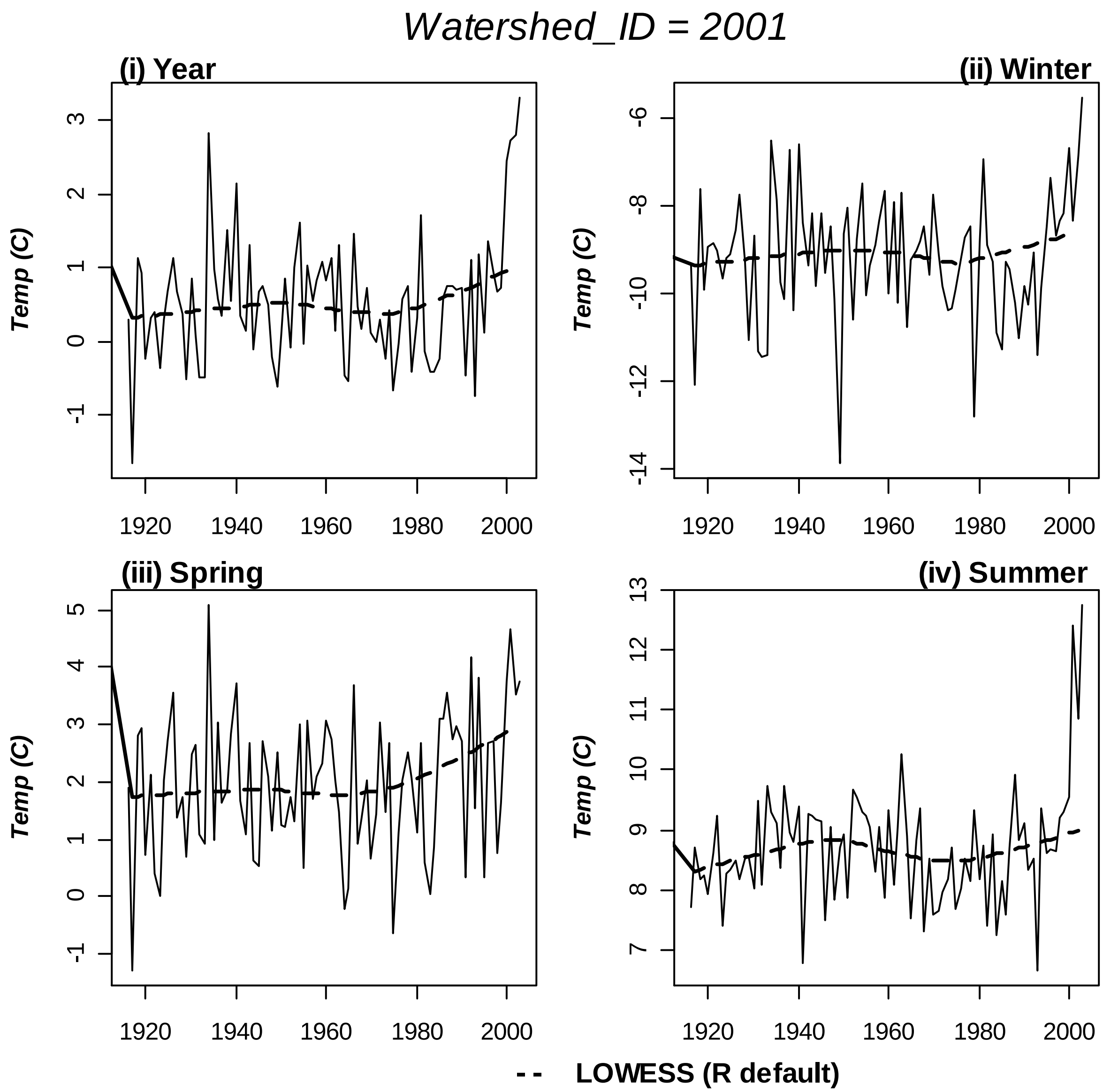

Figure 7.29. Temperature analyses for Little Cottonwood creek at Jordan River near Salt Lake City watershed (watershed_ID = 2001). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

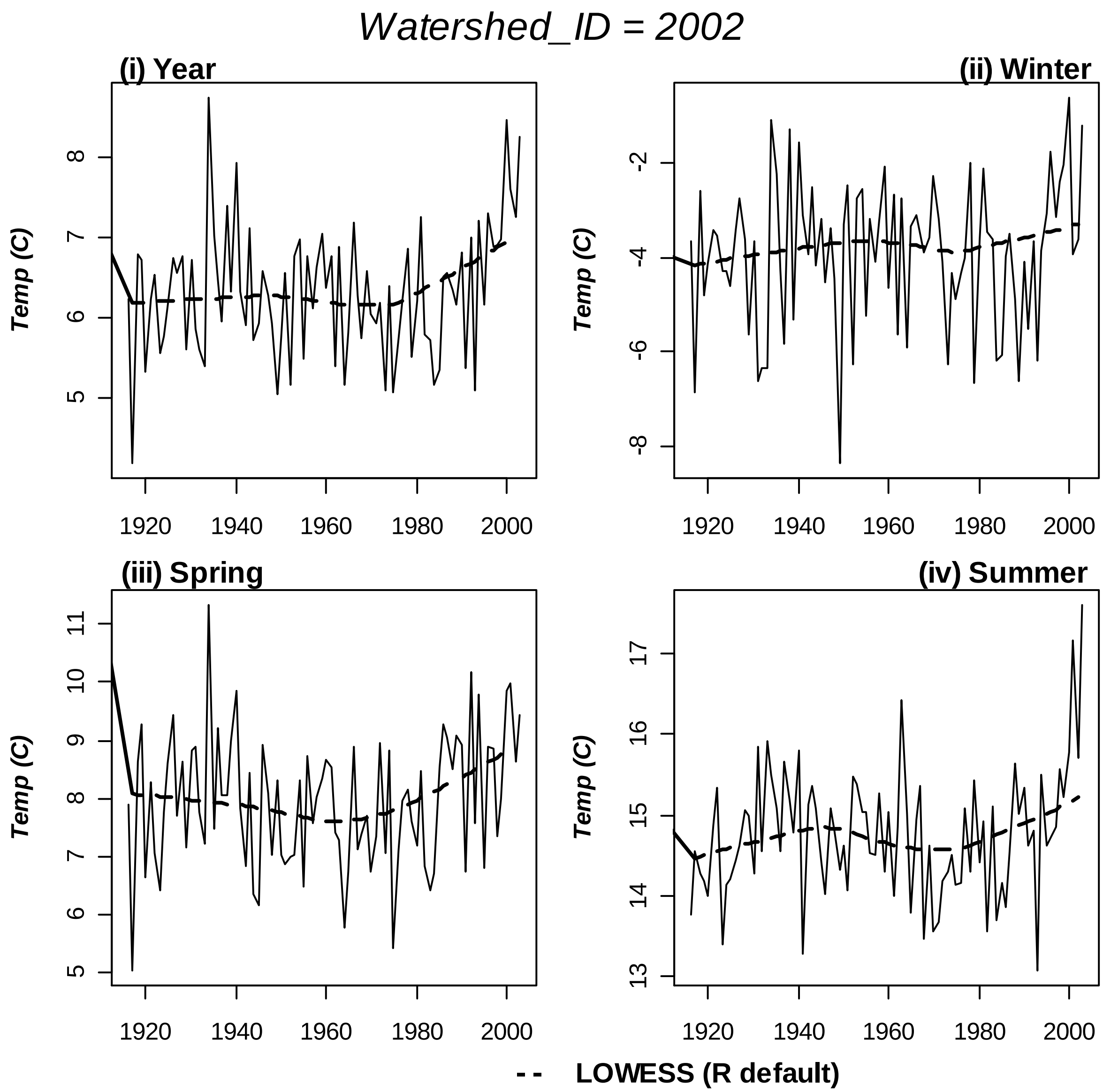

Figure 7.30. Temperature analyses for Jordan River & Surplus Canal at Salt Lake City watershed (watershed_ID = 2002). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

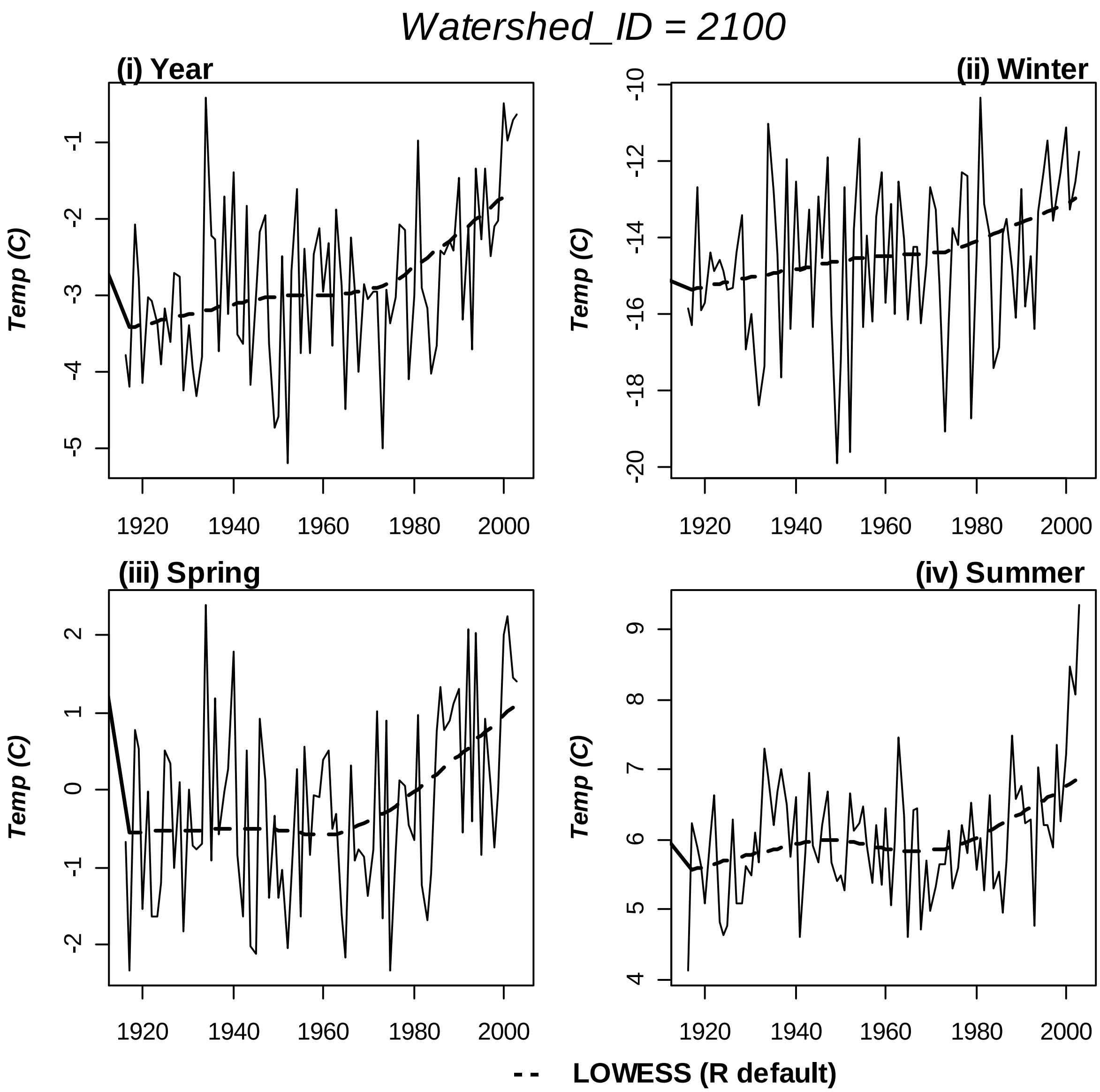

Figure 7.31. Temperature analyses for Whiterocks River near Whiterocks watershed (watershed_ID = 2100). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

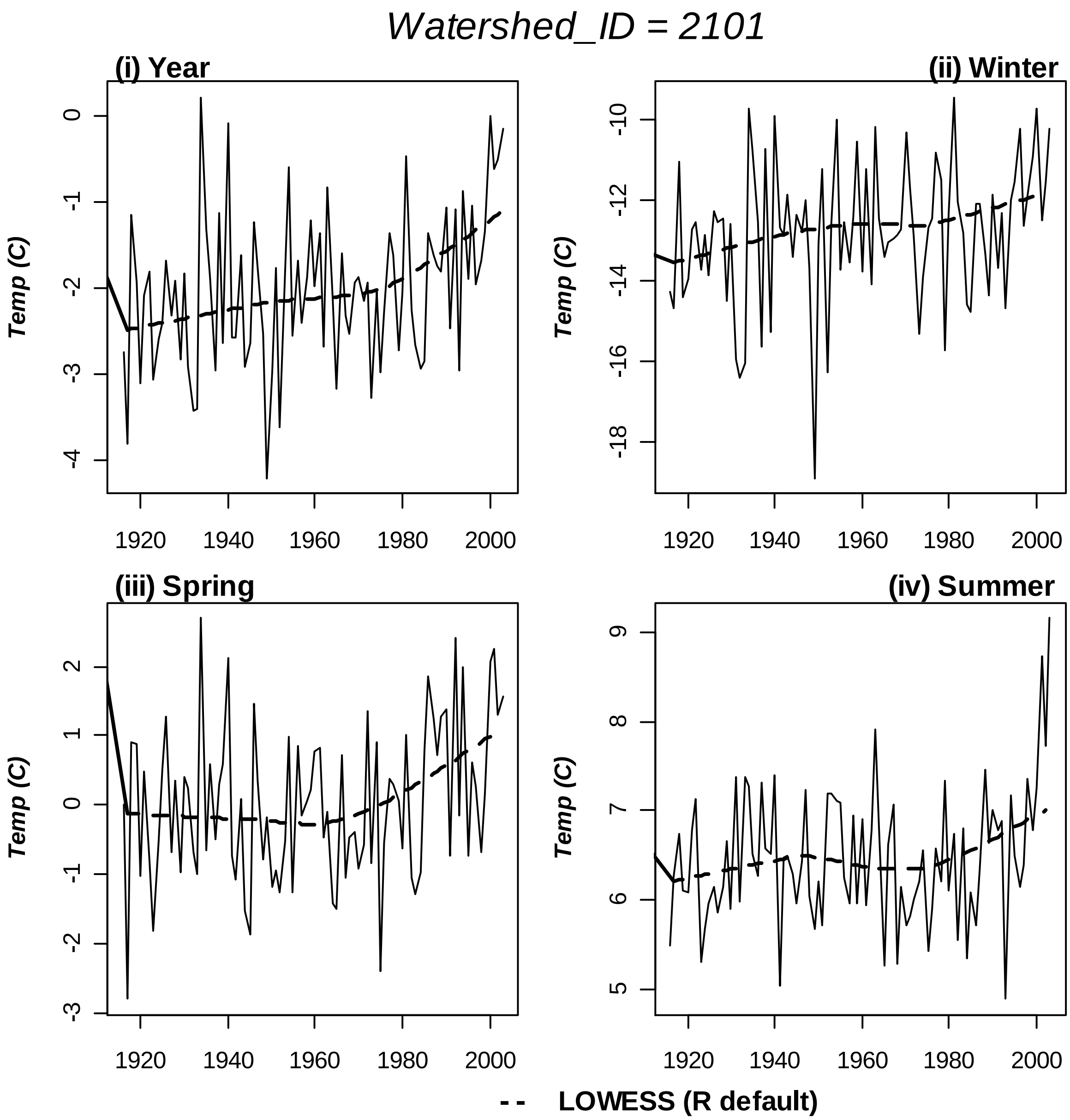

Figure 7.32. Temperature analyses for Rock Creek near Mountain Home watershed (watershed_ID = 2101). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

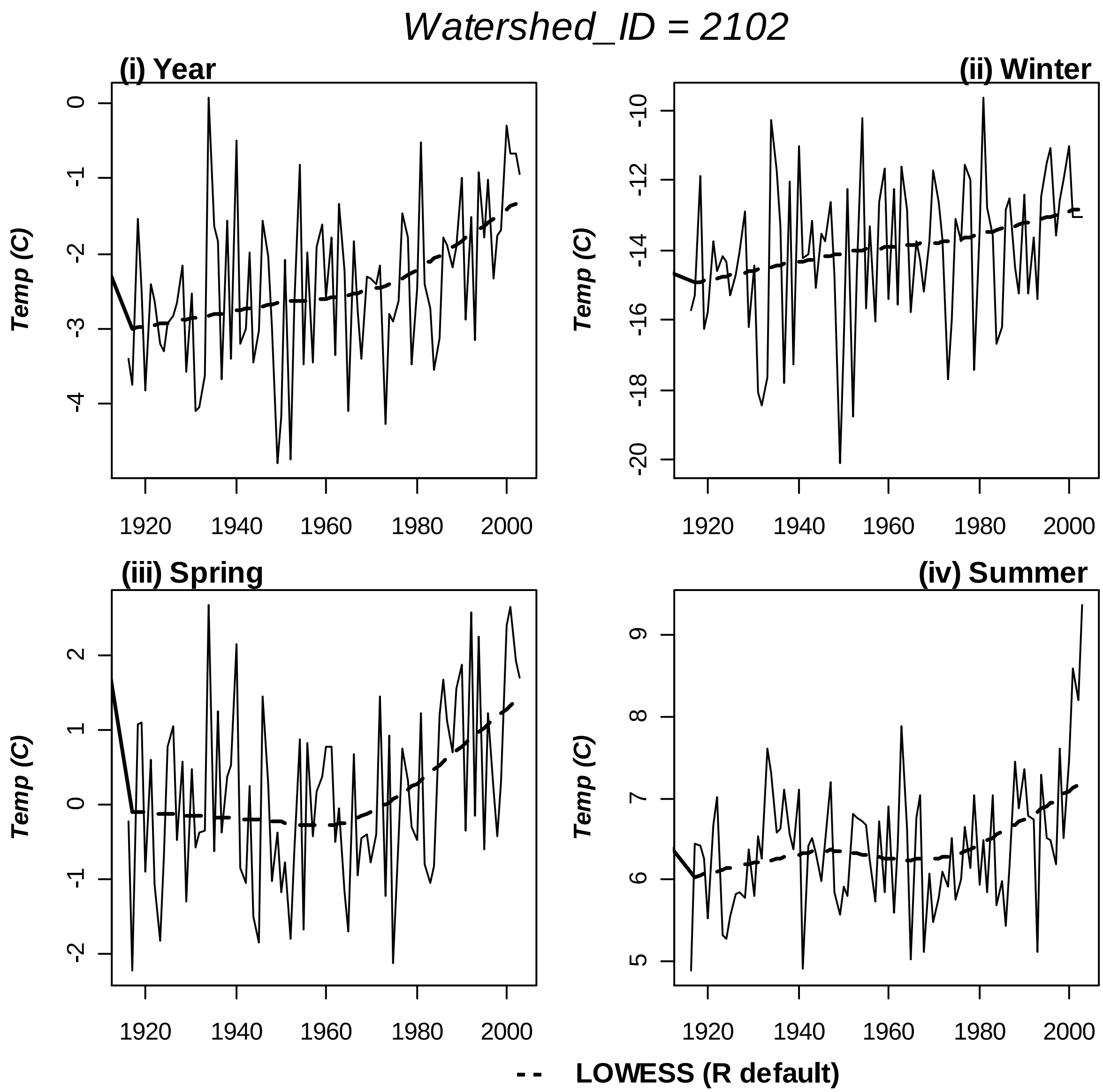

Figure 7.33. Temperature analyses for Yellowstone River near Altonah watershed (watershed_ID = 2102). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

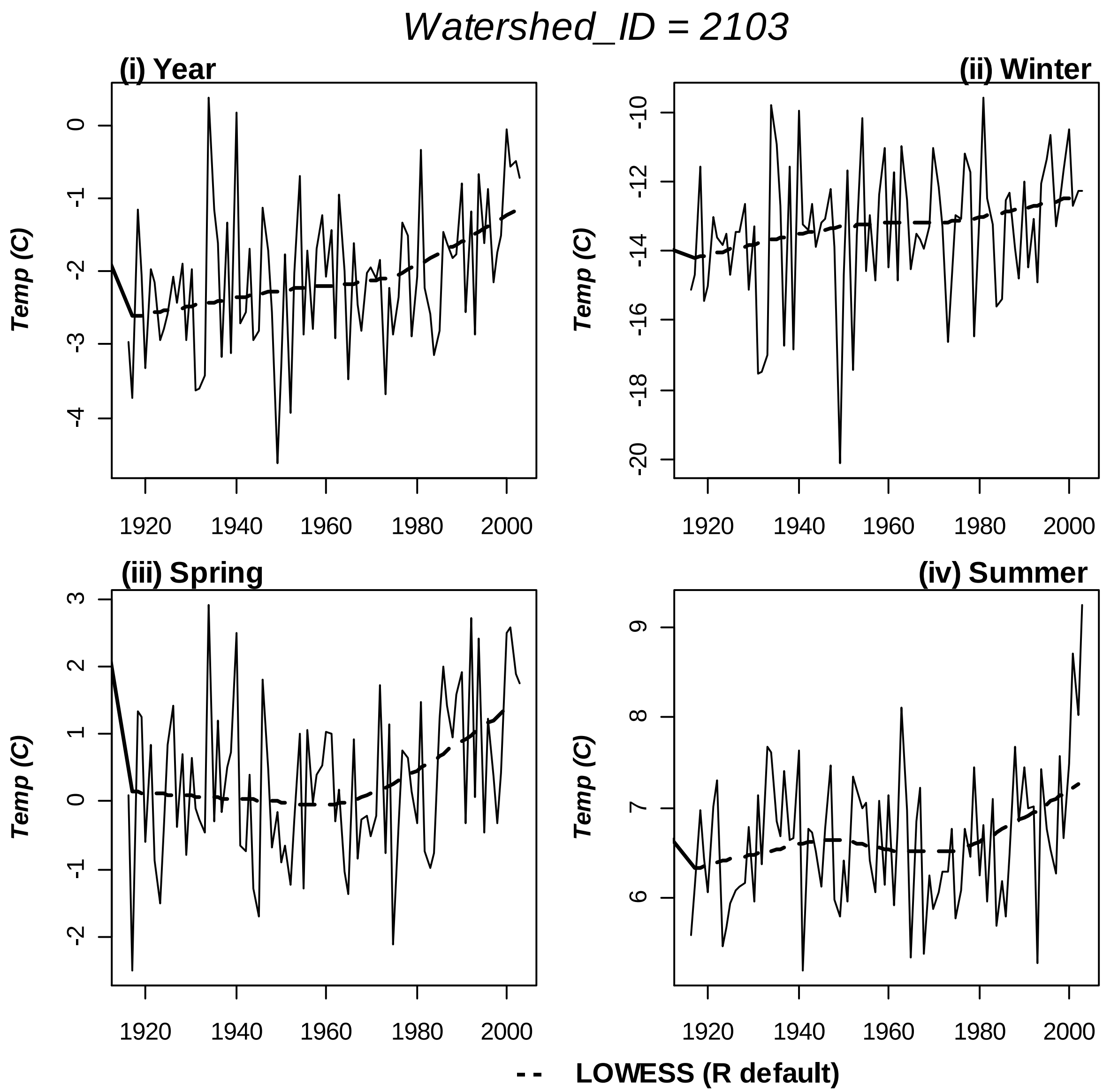

Figure 7.34. Temperature analyses for Lake Fork River below Moon Lake near Mountain Home watershed (watershed_ID = 2103). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

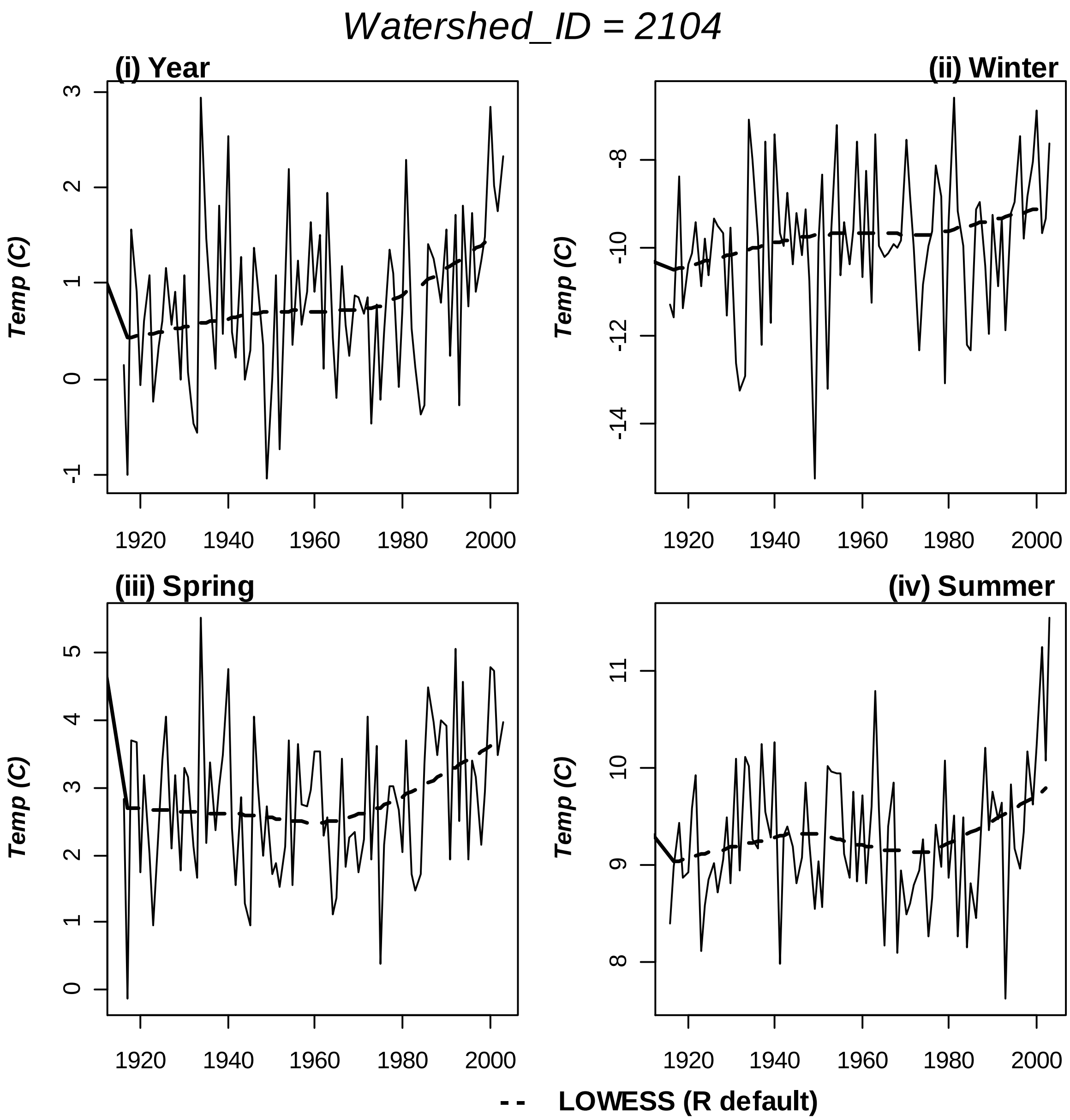

Figure 7.35. Temperature analyses for Duchesne River near Tabiona watershed (watershed_ID = 2104). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

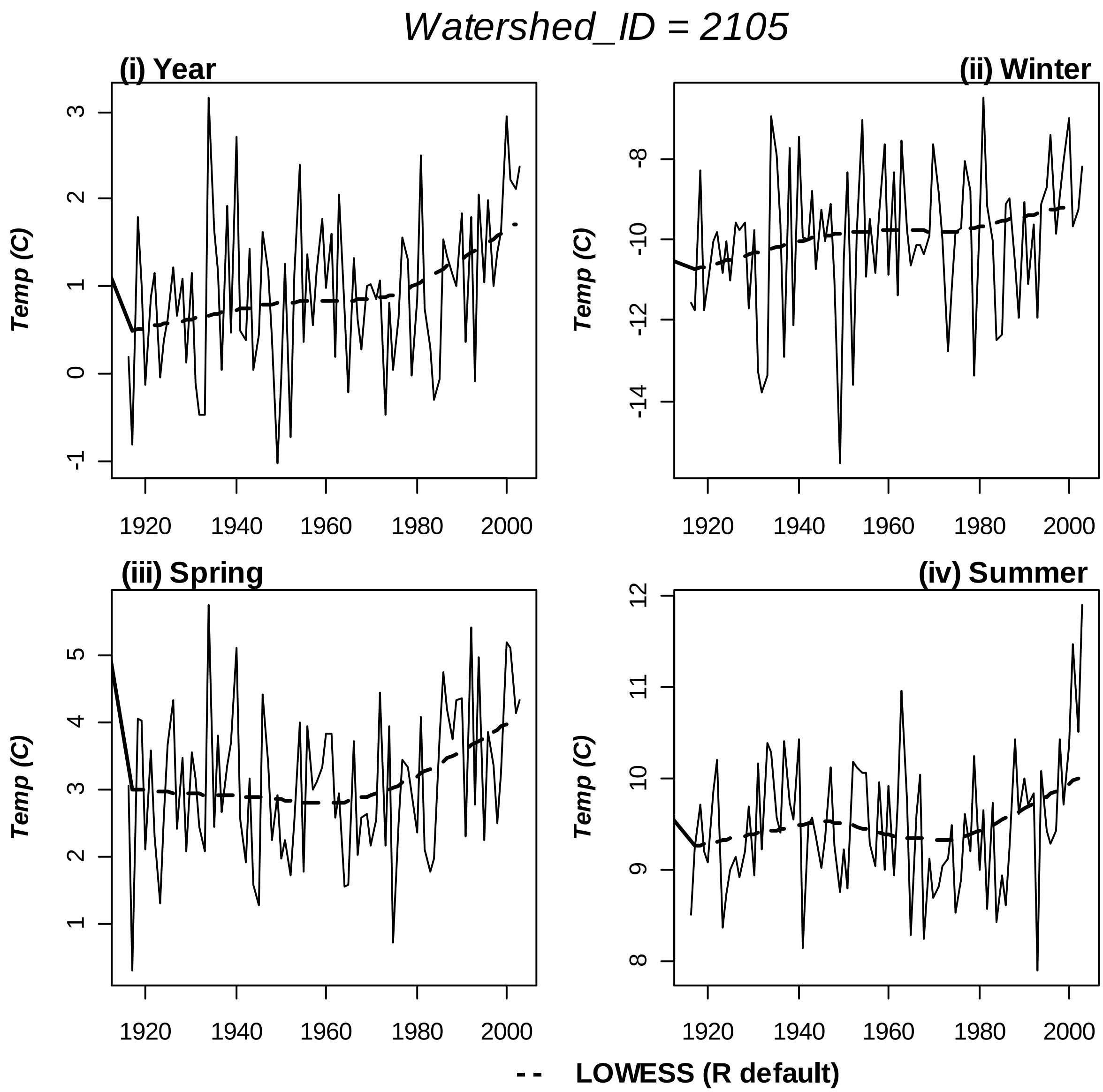

Figure 7.36. Temperature analyses for Duchesne River above Knight Diversion near Duchesne watershed (watershed_ID = 2105). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

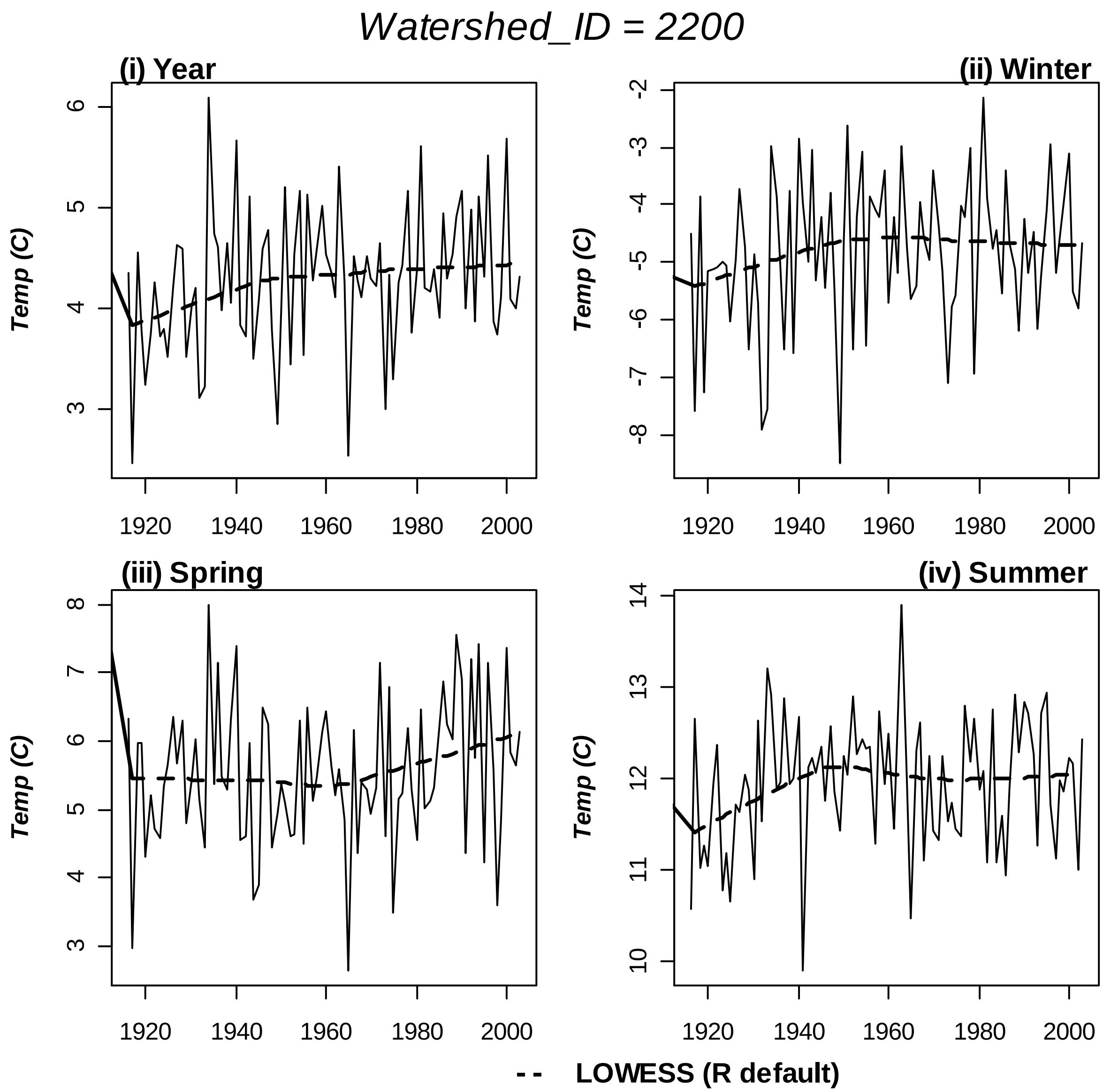

Figure 7.37. Temperature analyses for Sevier River Kingston watershed (watershed_ID = 2200). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

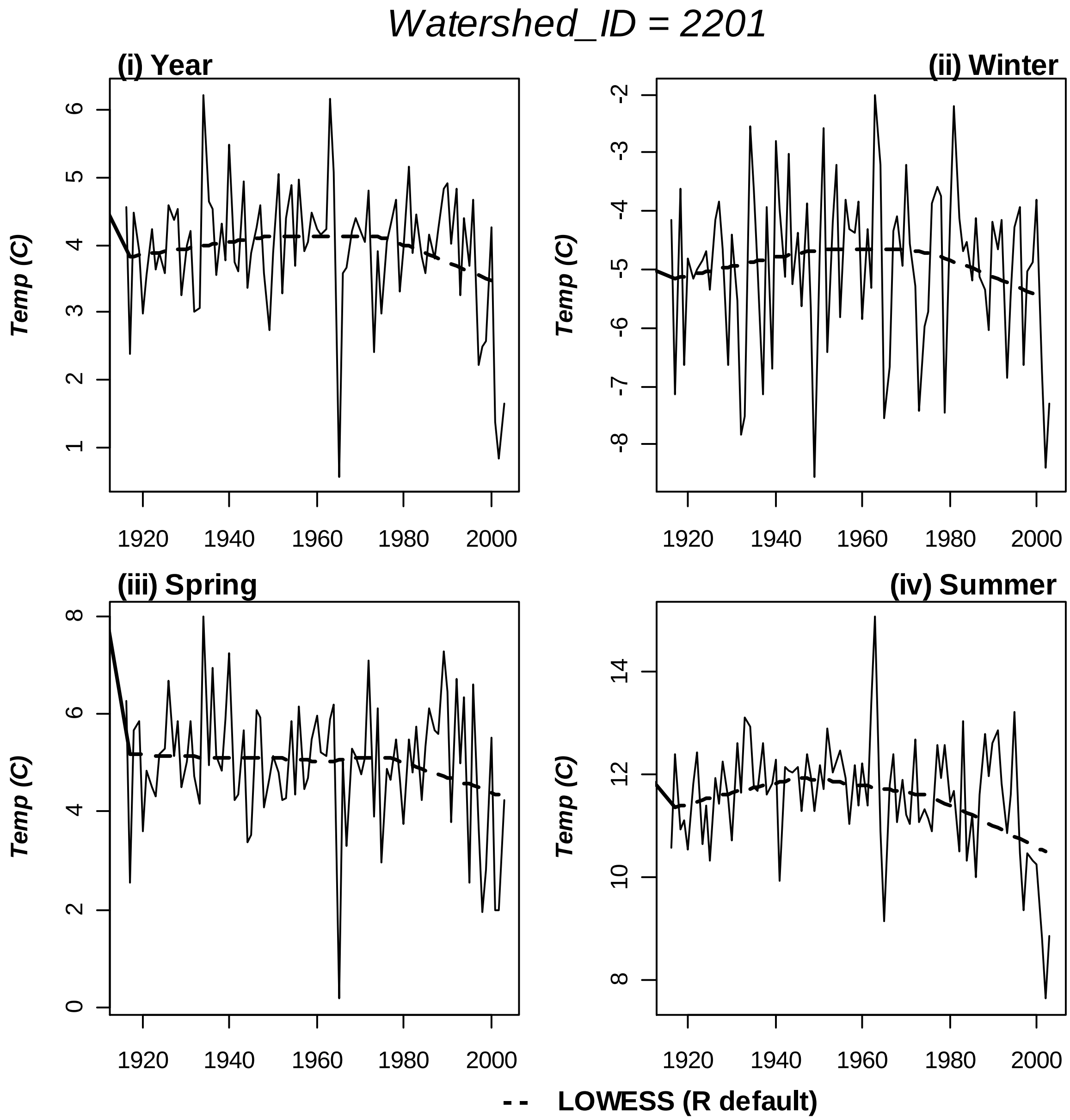

Figure 7.38. Temperature analyses for Sevier River at Hatch watershed (watershed_ID = 2201). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.

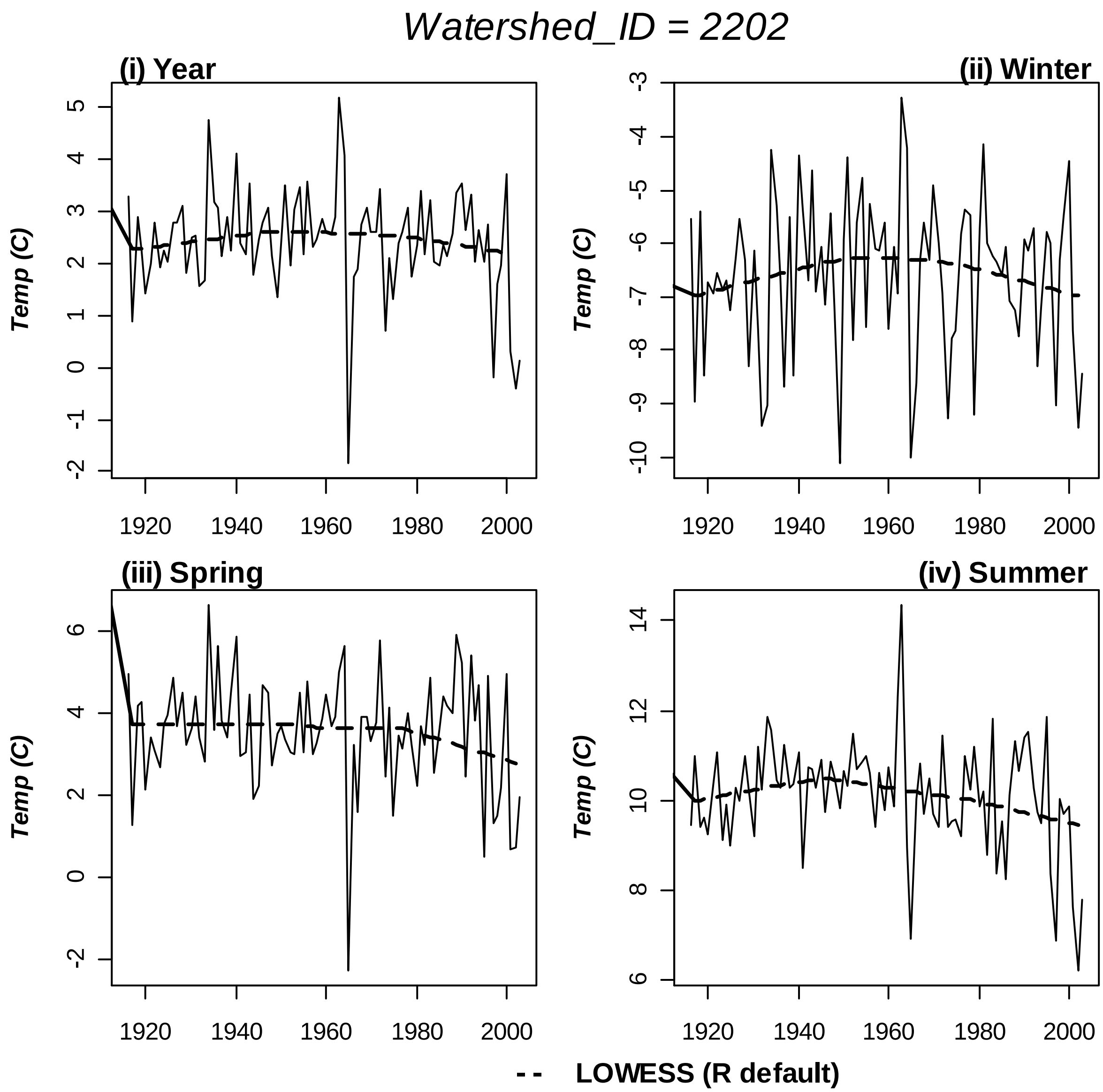

Figure 7.39. *Temperature analyses for Mammoth Creek above west Hatch ditch near Hatch watershed (watershed_ID = 2202). Panel (i) gives the average water year temperature time series over the watershed. Panel (ii) gives the annual average temperature in winter season (November, December, January, and February) time series. Panel (iii) gives the annual average temperature in spring season (March, April, May, and June) time series. Panel (iv) gives the annual average temperature in summer season (July, August, September, and October) time series.*

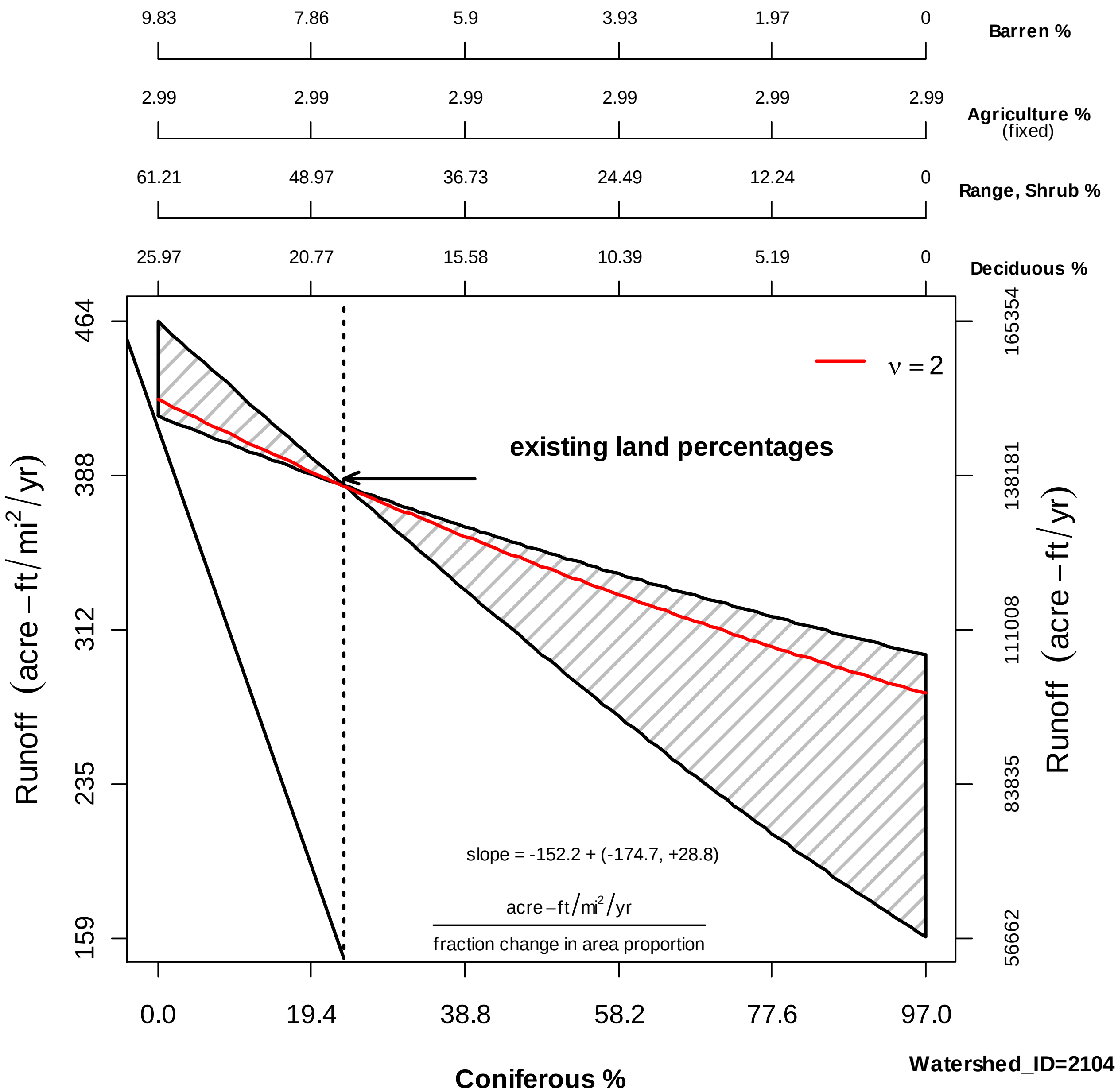

Figure 8.1. Runoff sensitivity to change in Coniferous land cover percentage in the Duchense River near Tabiona watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 356.37 mi^2.

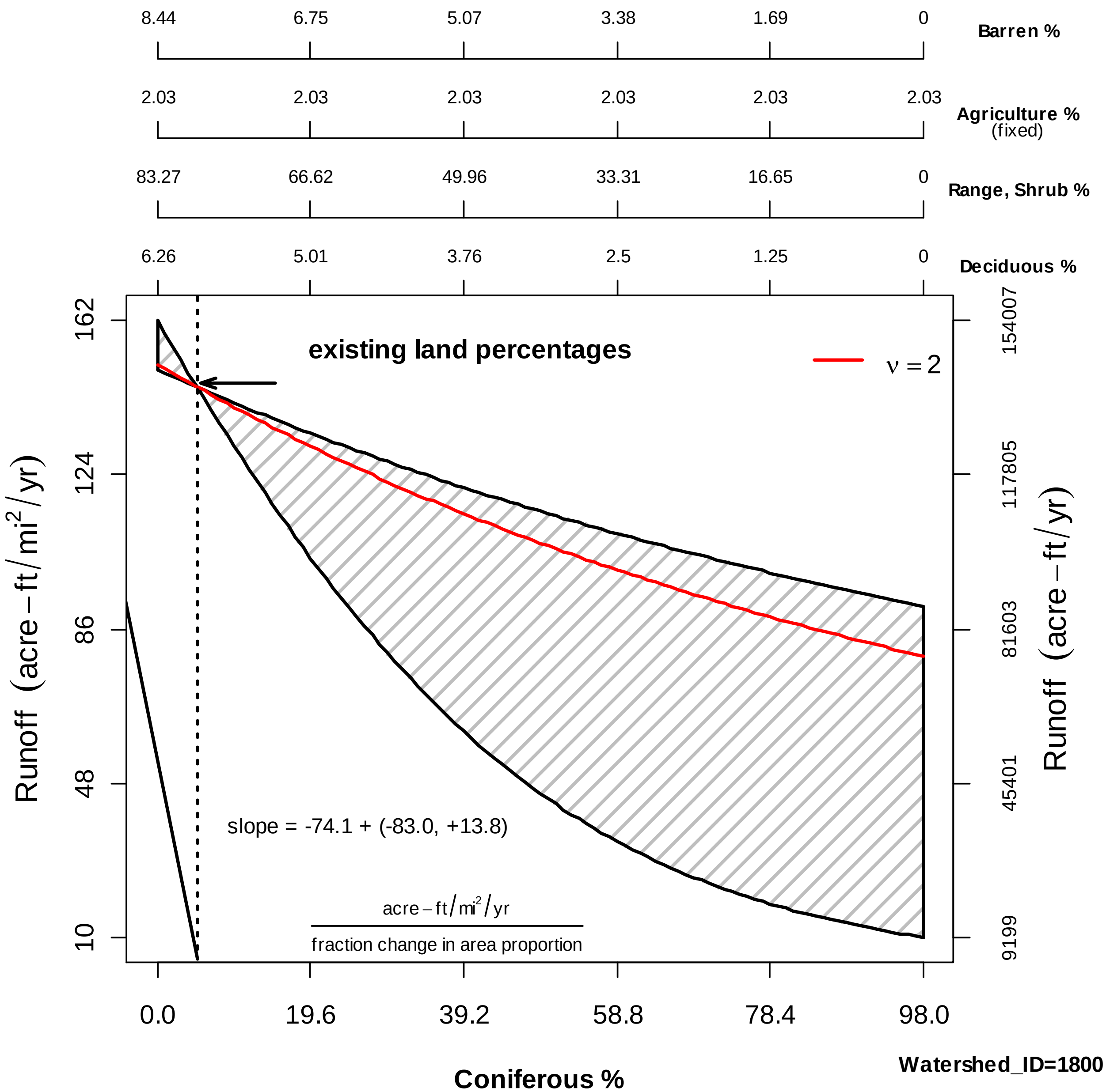

Figure 8.2. Runoff sensitivity to change in Coniferous land cover percentage in the Virgin River near Virgin watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 948.32 mi^2.

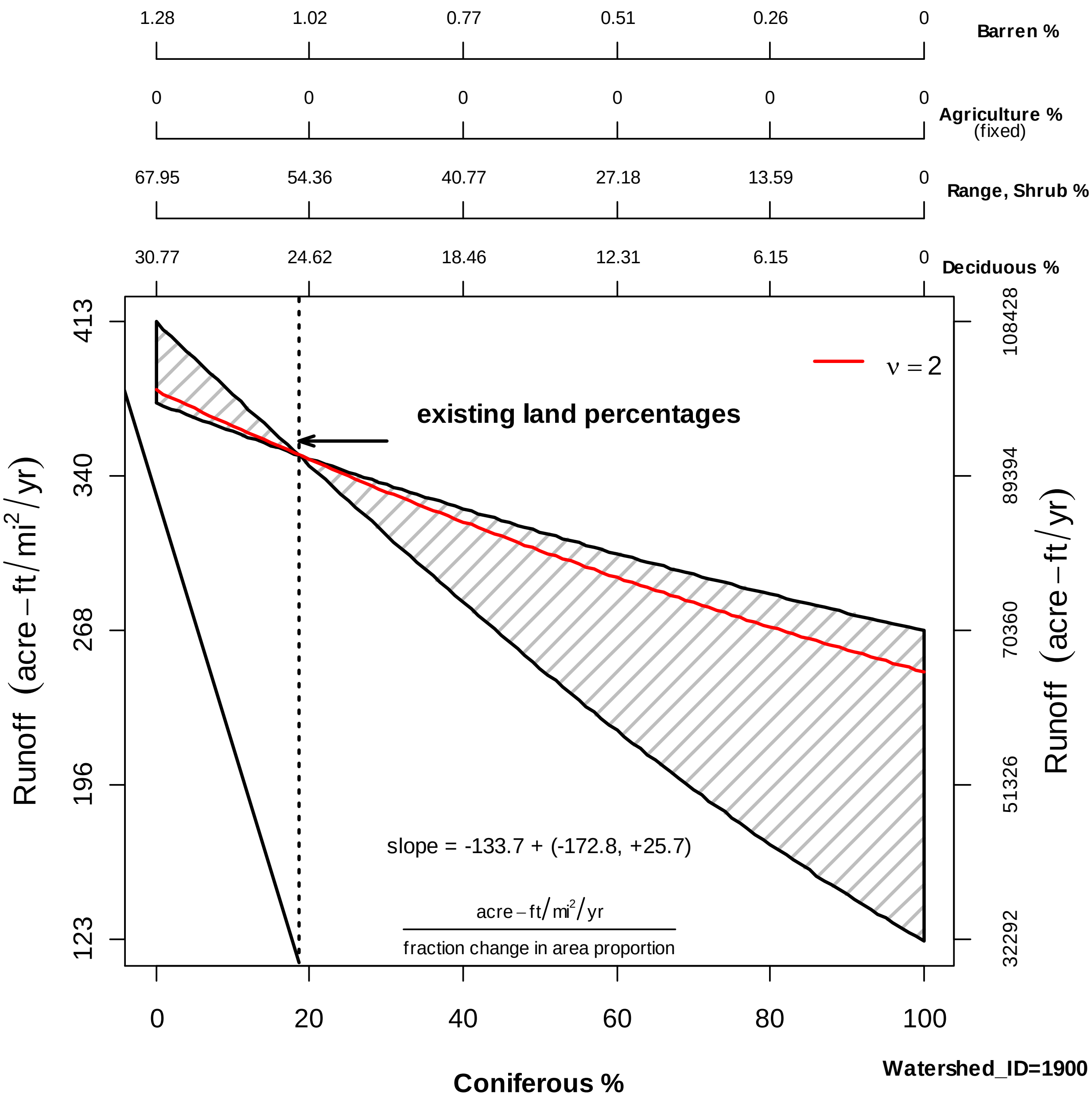

Figure 8.3. Runoff sensitivity to change in Coniferous land cover percentage in the Blacksmith Fork near Hyrum watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 262.54 mi^2.

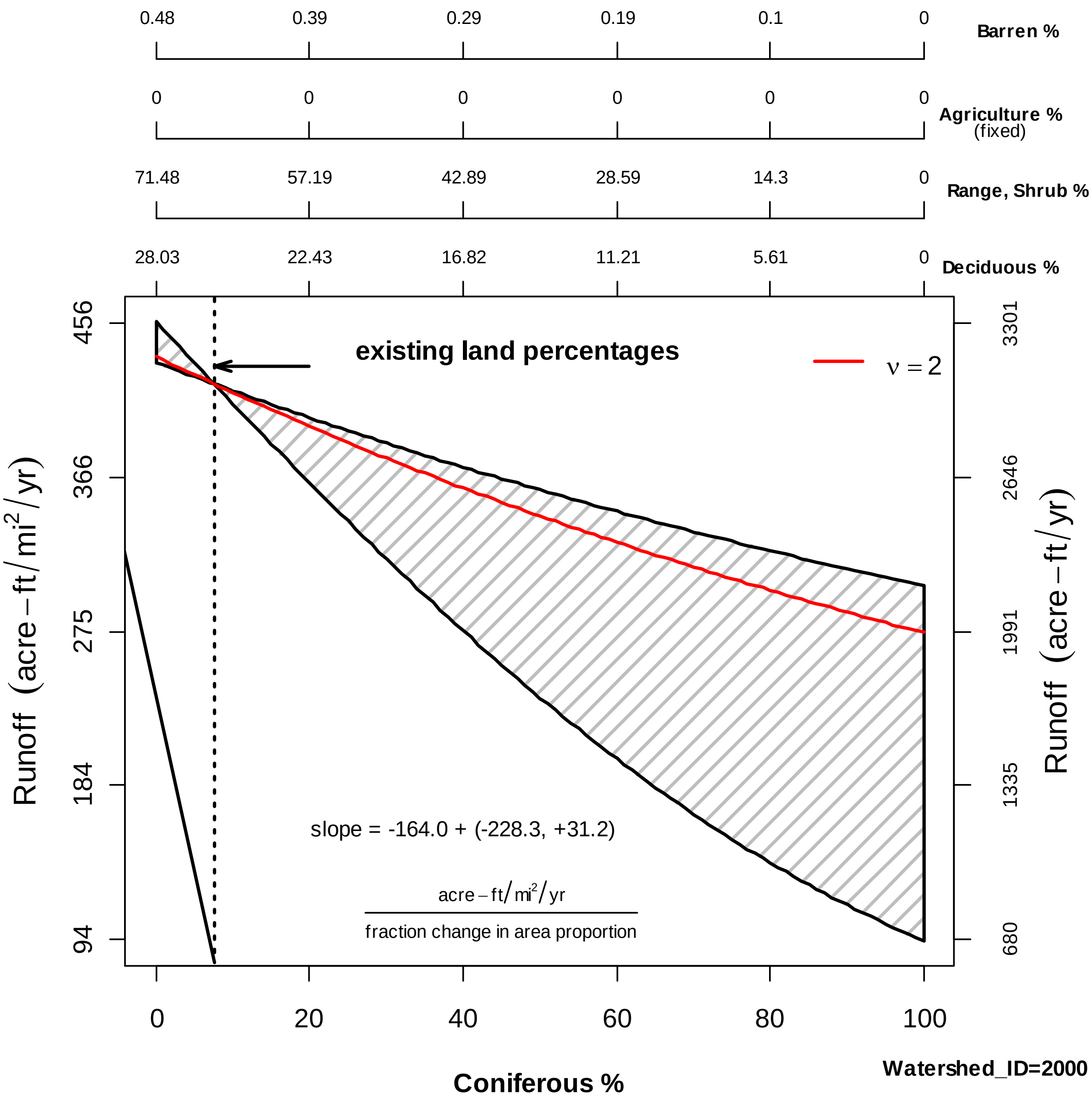

Figure 8.4. Runoff sensitivity to change in Coniferous land cover percentage in the Red Butte creek at Fort Douglas near SLC watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 7.24 mi^2.

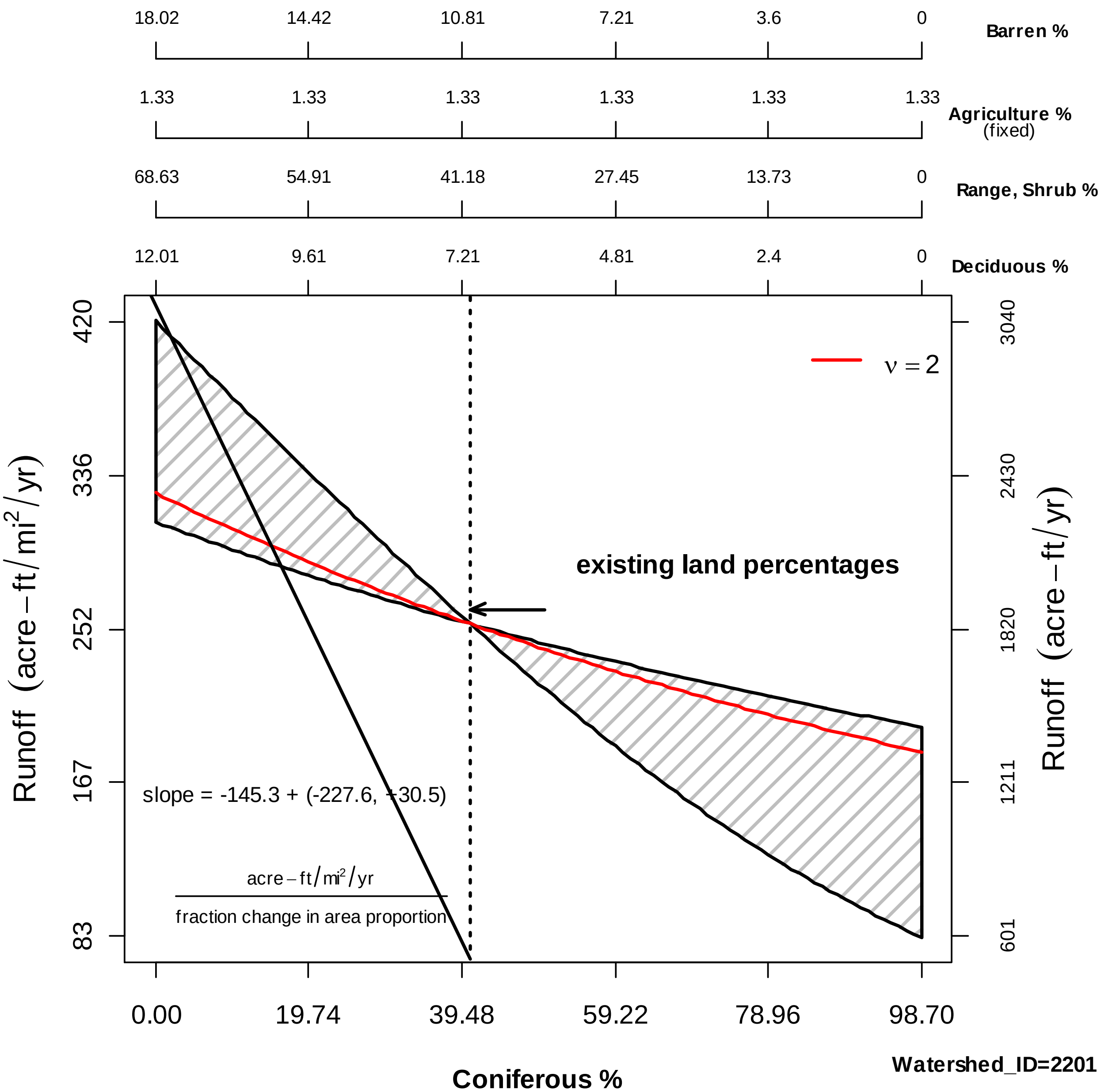

Figure 8.5. Runoff sensitivity to change in Coniferous land cover percentage in the Sevier River near Hatch watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with $\pm$ bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 335.21 mi^2.

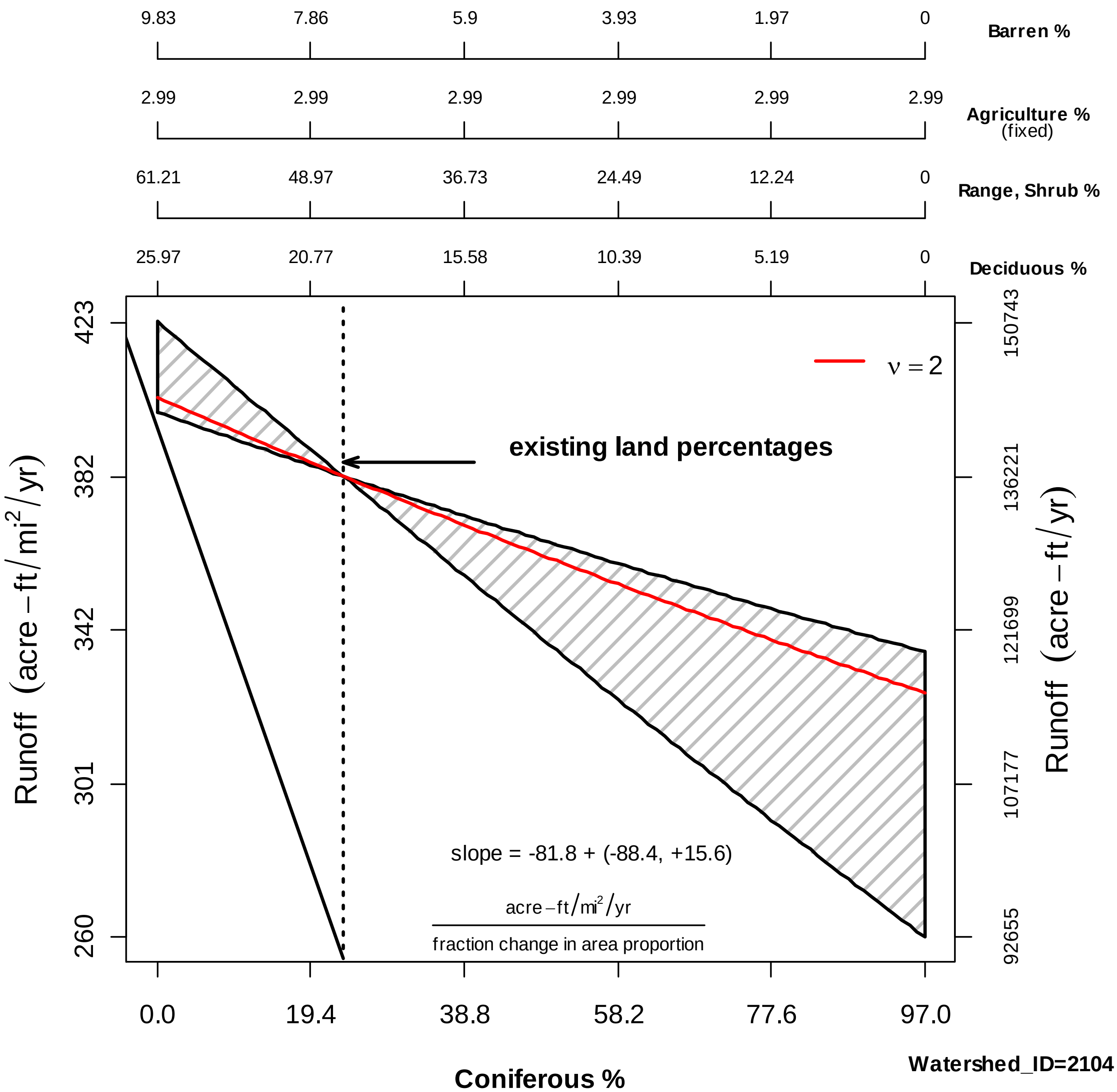

Figure 8.6. Runoff sensitivity to change in Coniferous land cover percentage in the Duchense River near Tabiona watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at ν = 2 with ± bounds from ν = 1.5 to ν = 10. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 356.37 mi^2.

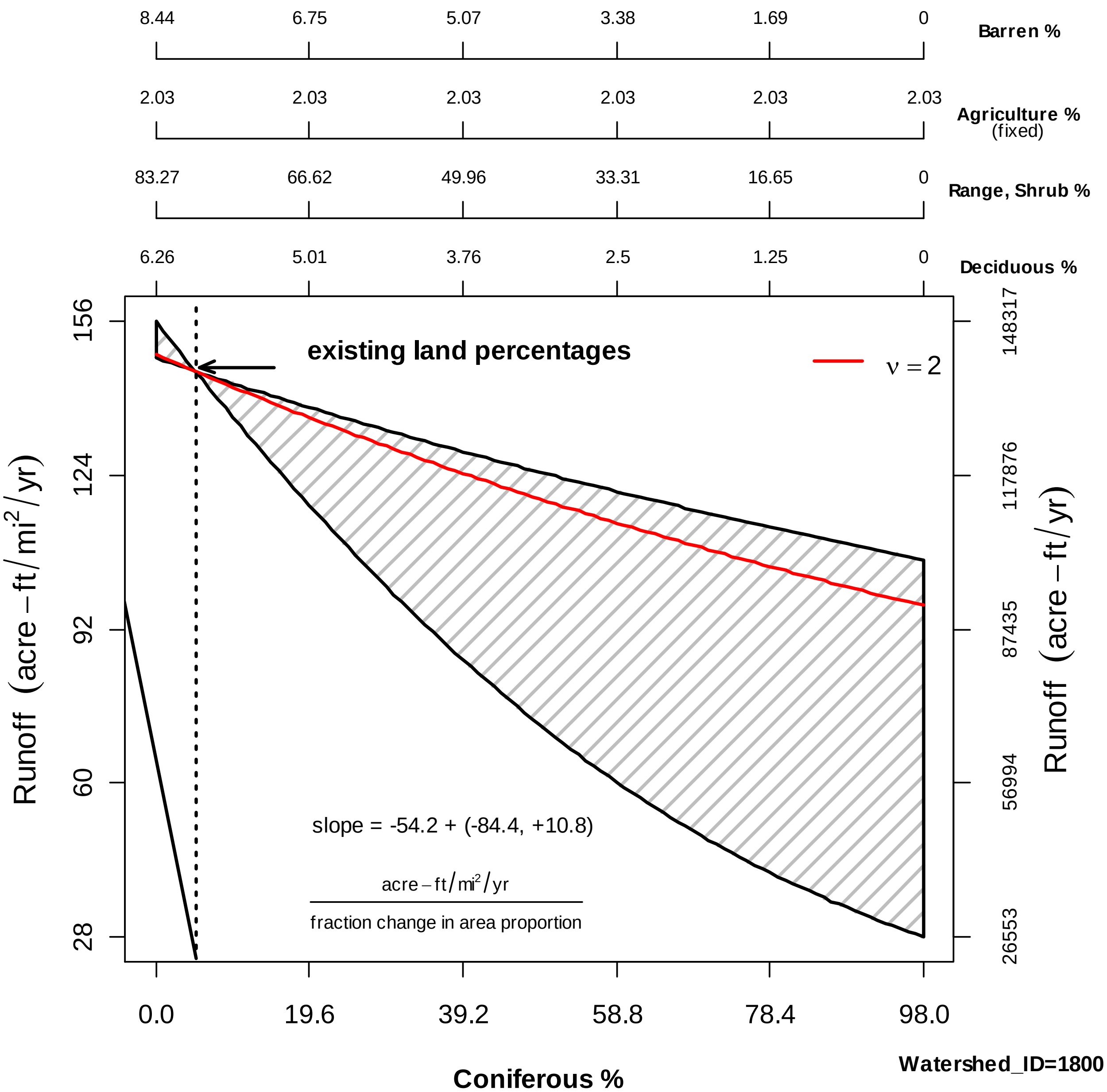

Figure 8.7. Runoff sensitivity to change in Coniferous land cover percentage in the Virgin River near Virgin watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 948.32 mi^2.

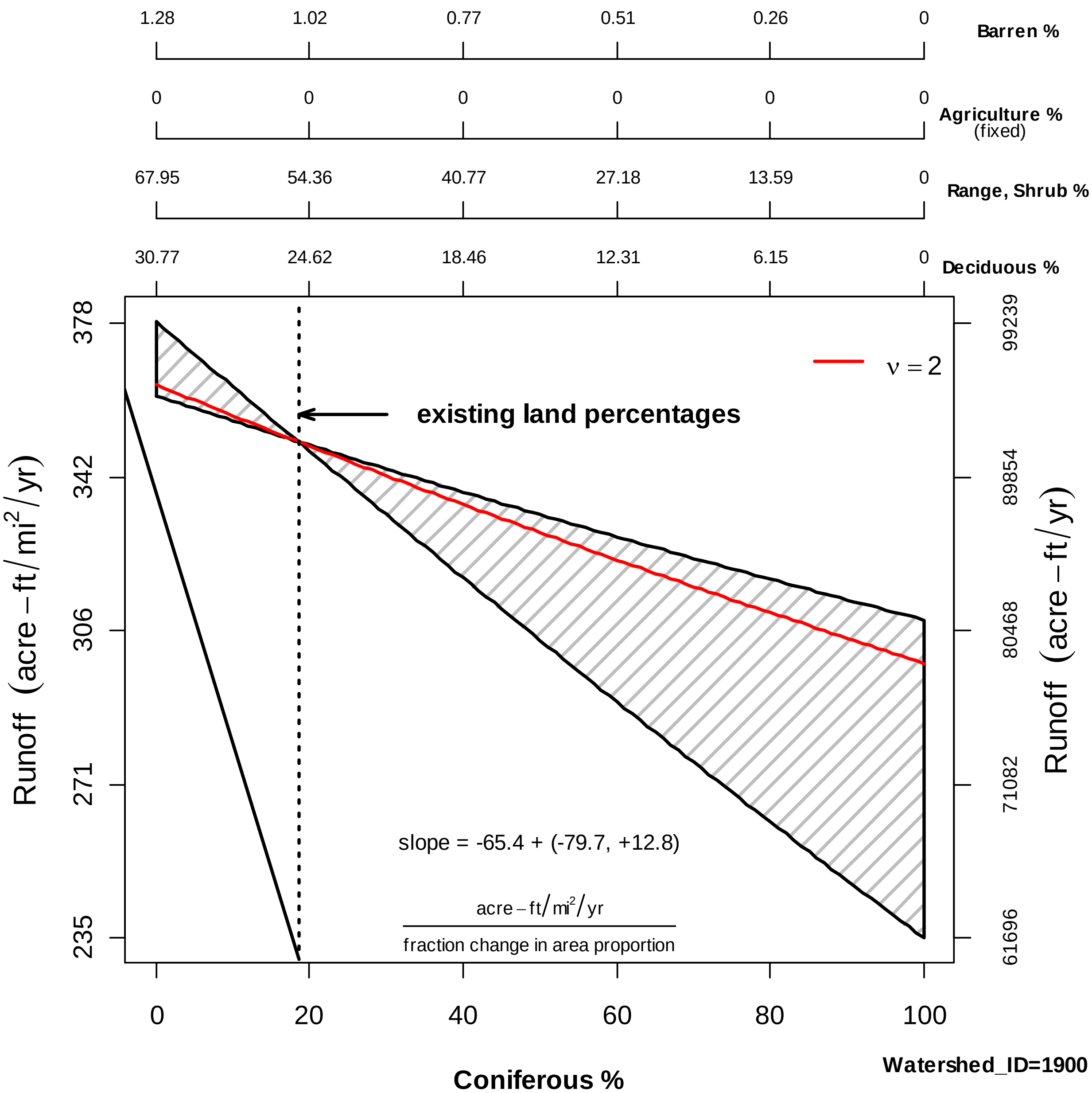

Figure 8.8. Runoff sensitivity to change in Coniferous land cover percentage in the Blacksmith Fork near Hyrum watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 262.54 mi^2.

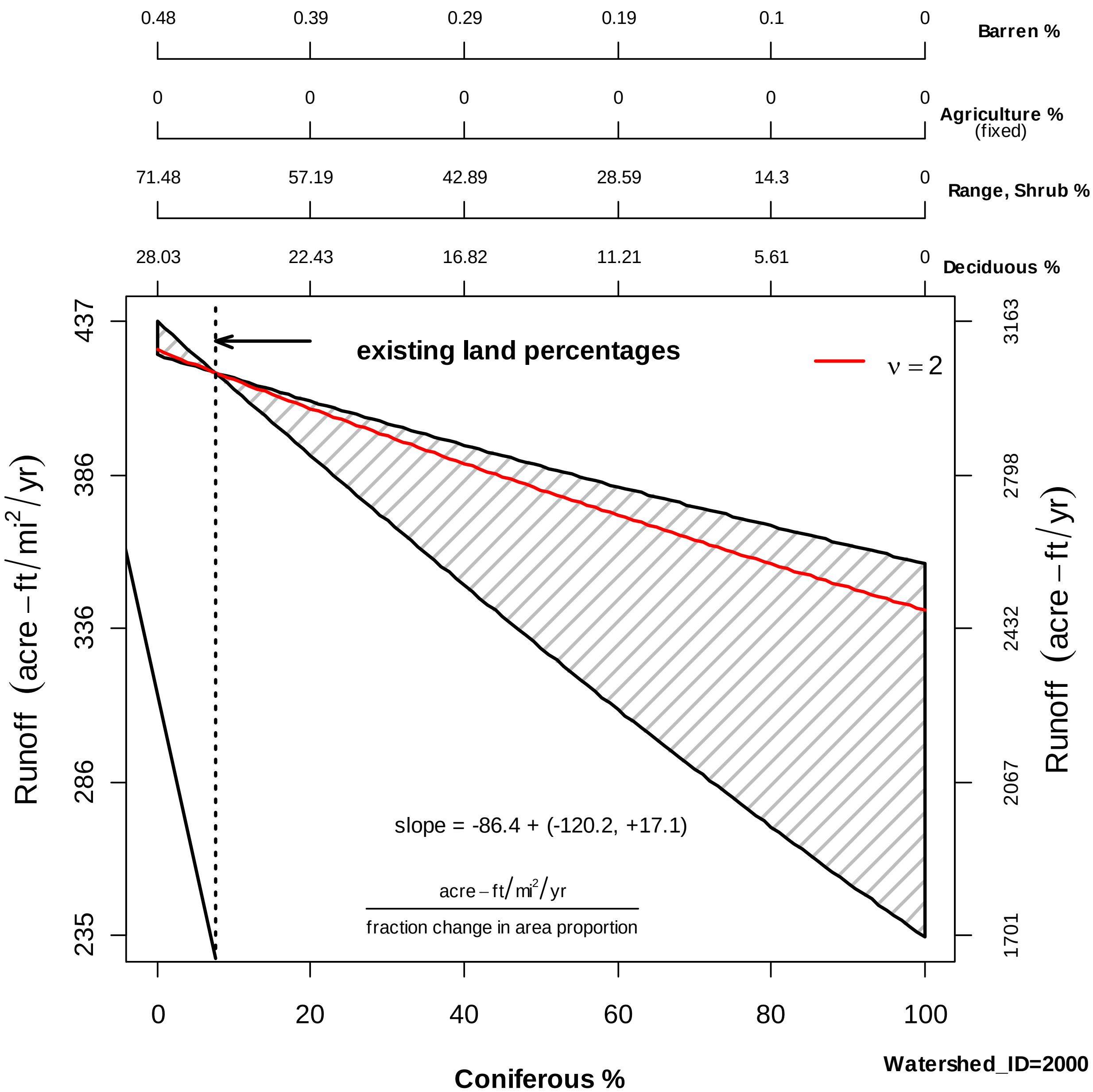

Figure 8.9. Runoff sensitivity to change in Coniferous land cover percentage in the Red Butte creek at Fort Douglas near SLC watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 7.24 mi^2.

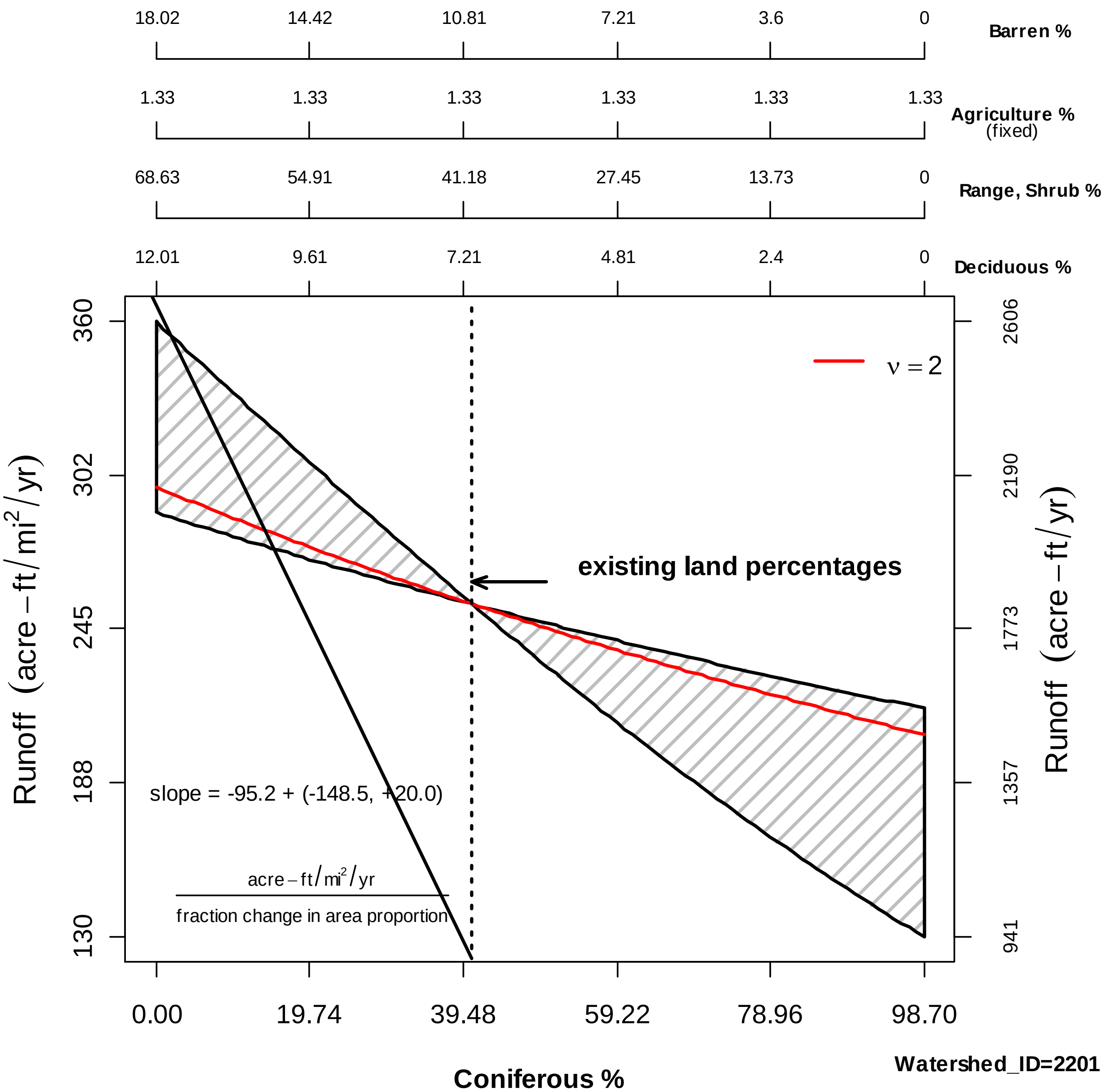

Figure 8.10. Runoff sensitivity to change in Coniferous land cover percentage in the Sevier River near Hatch watershed. Percentage of Agriculture held fixed while percentages of other land covers adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with $\pm$ bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0 (fixed). The watershed area is 335.21 mi^2.

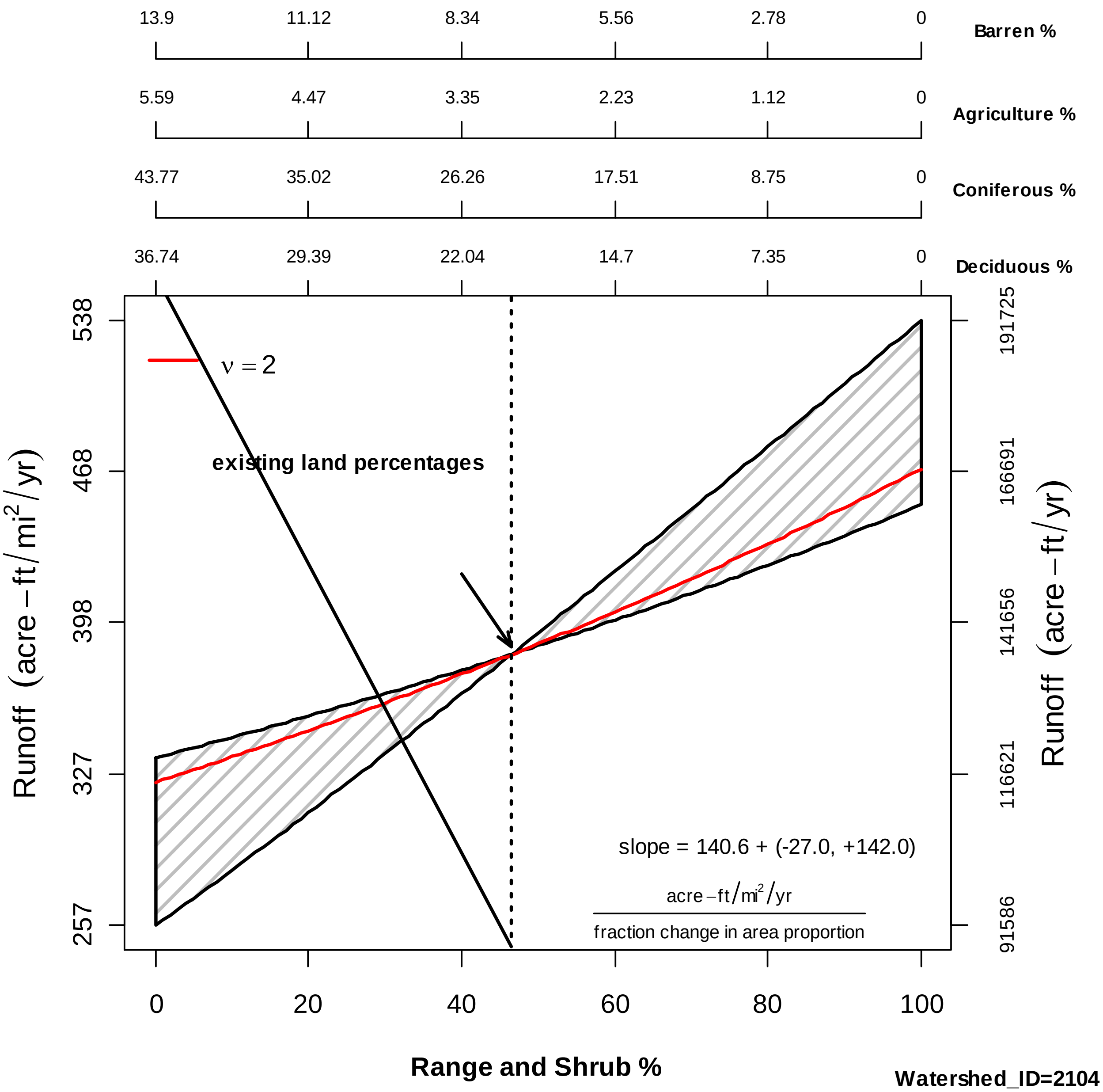

Figure 8.11. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Duchense River near Tabiona watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 356.37 mi^2.

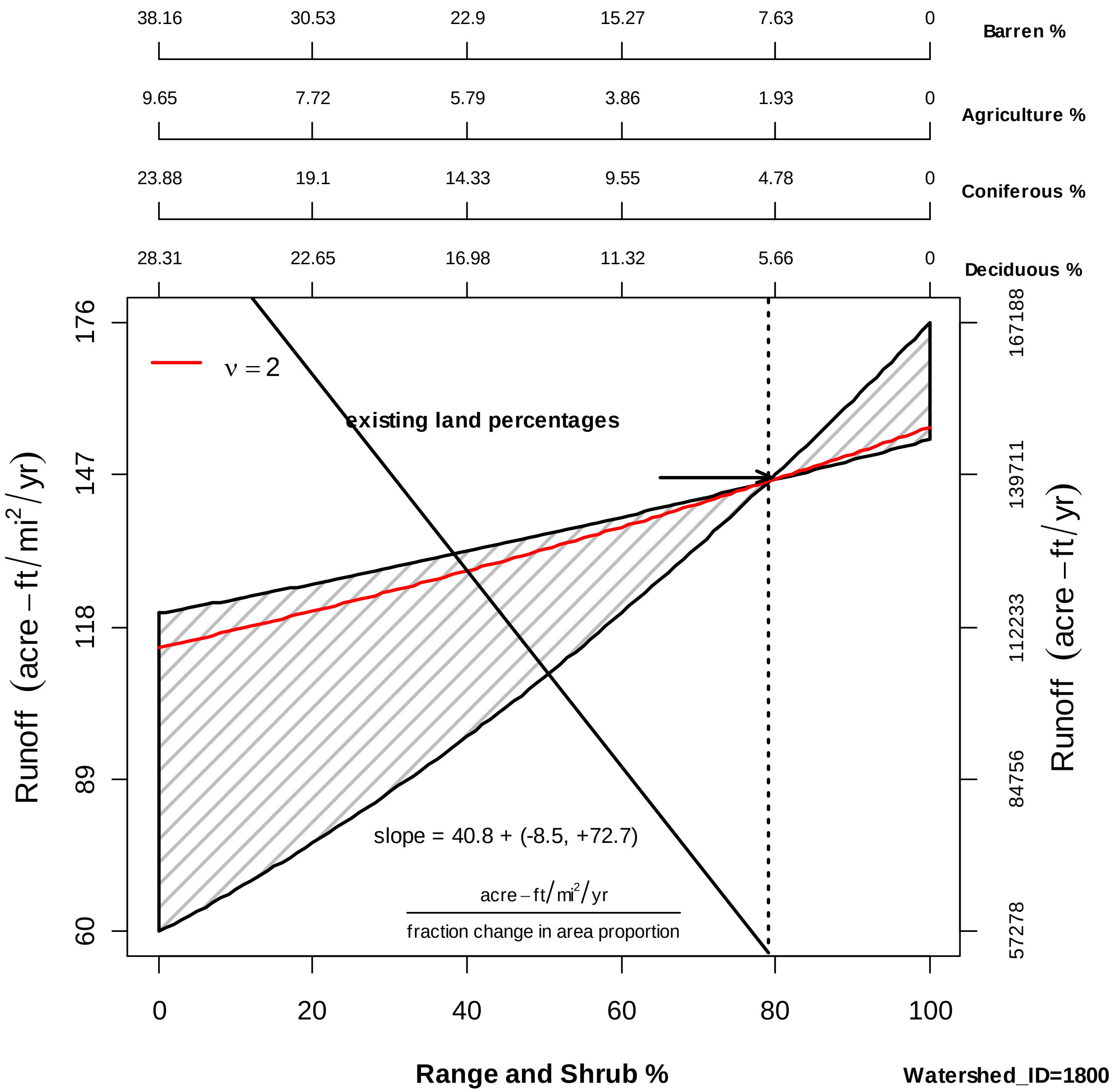

Figure 8.12. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Virgin River near Virgin watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 948.32 mi^2.

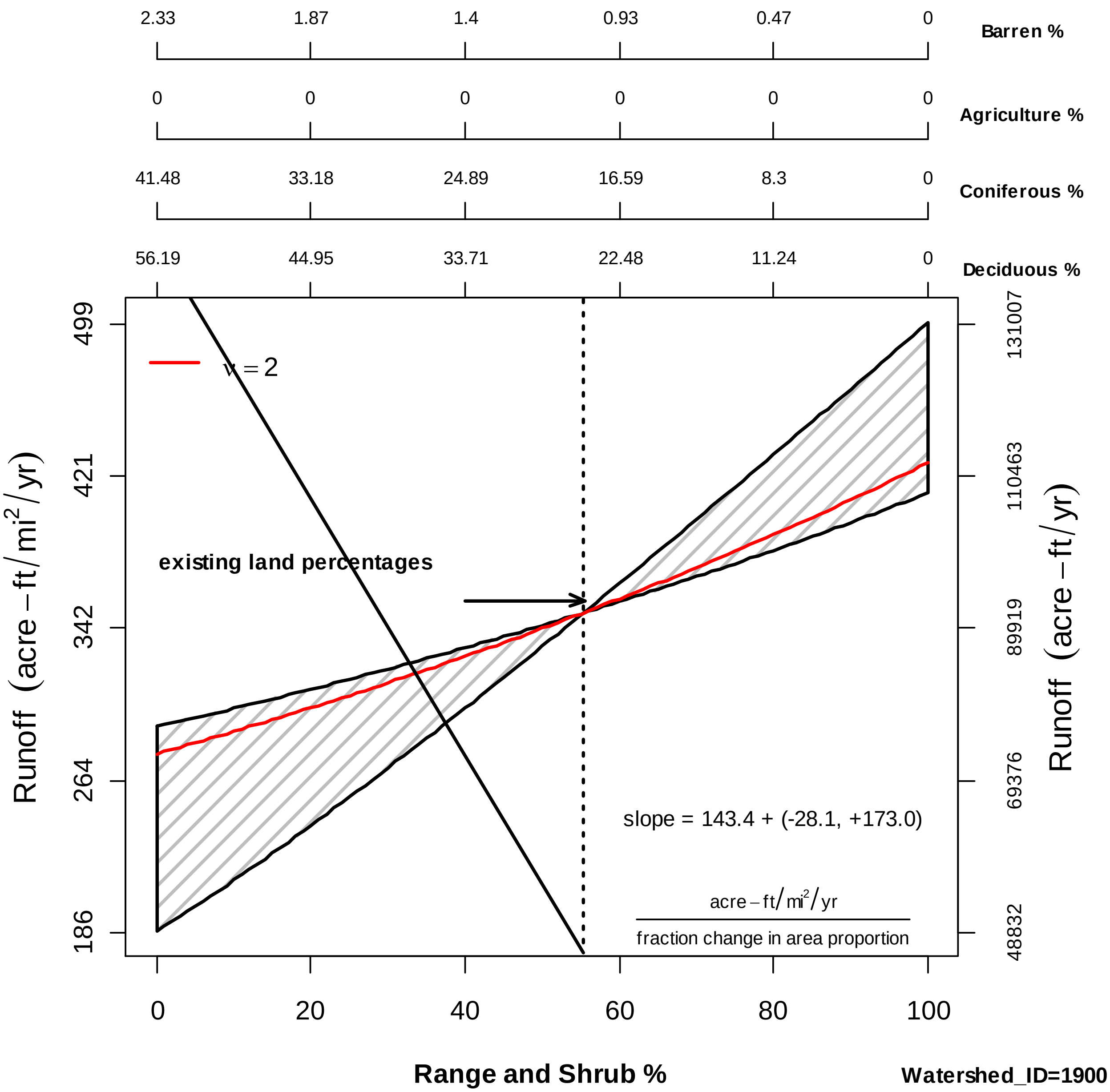

Figure 8.13. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Blacksmith Fork near Hyrum watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 262.54 mi^2.

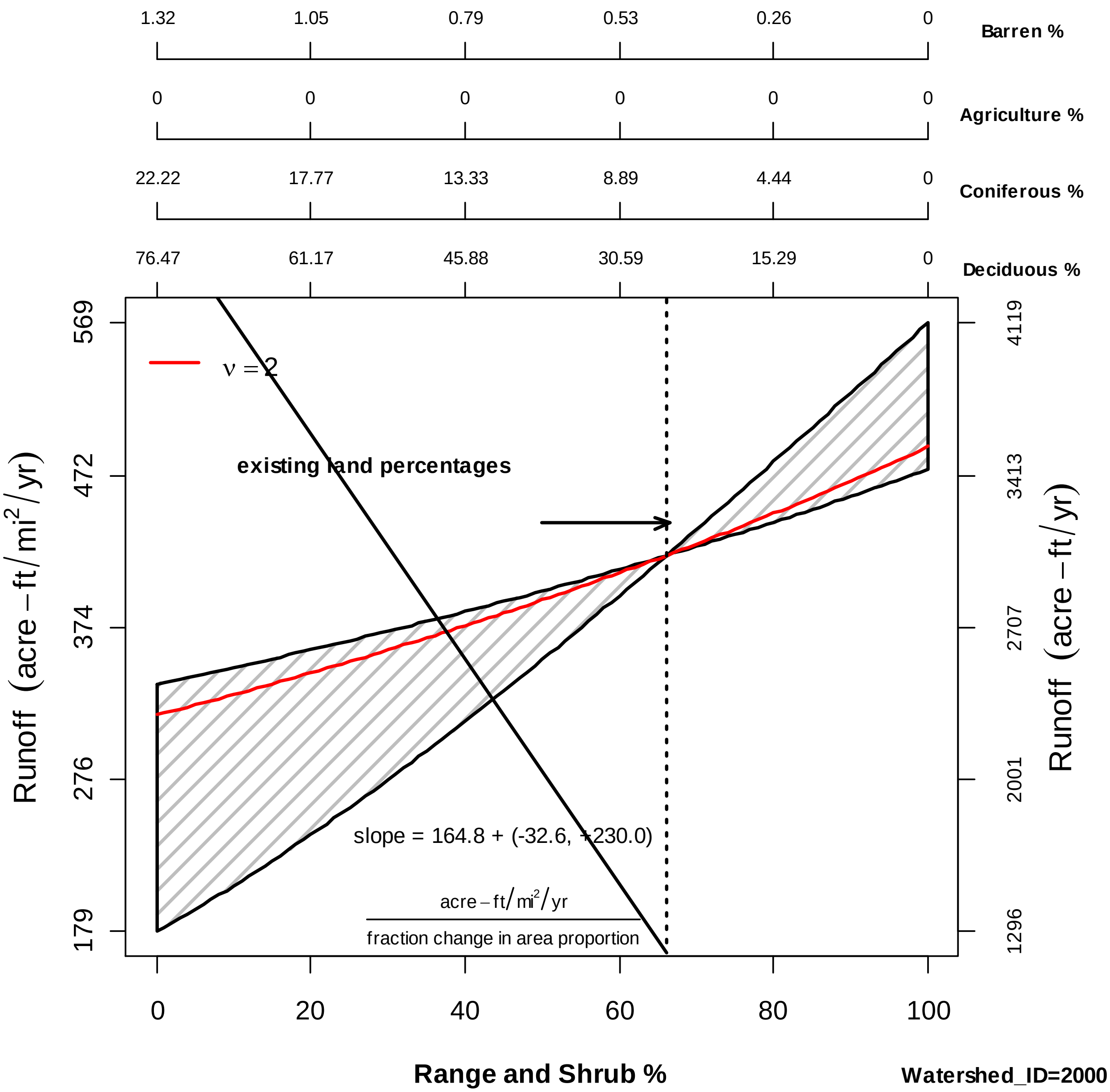

Figure 8.14. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Red Butte creek at Fort Douglas near SLC watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at ν = 2 with ± bounds from ν = 1.5 to ν = 10. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 7.24 mi^2.

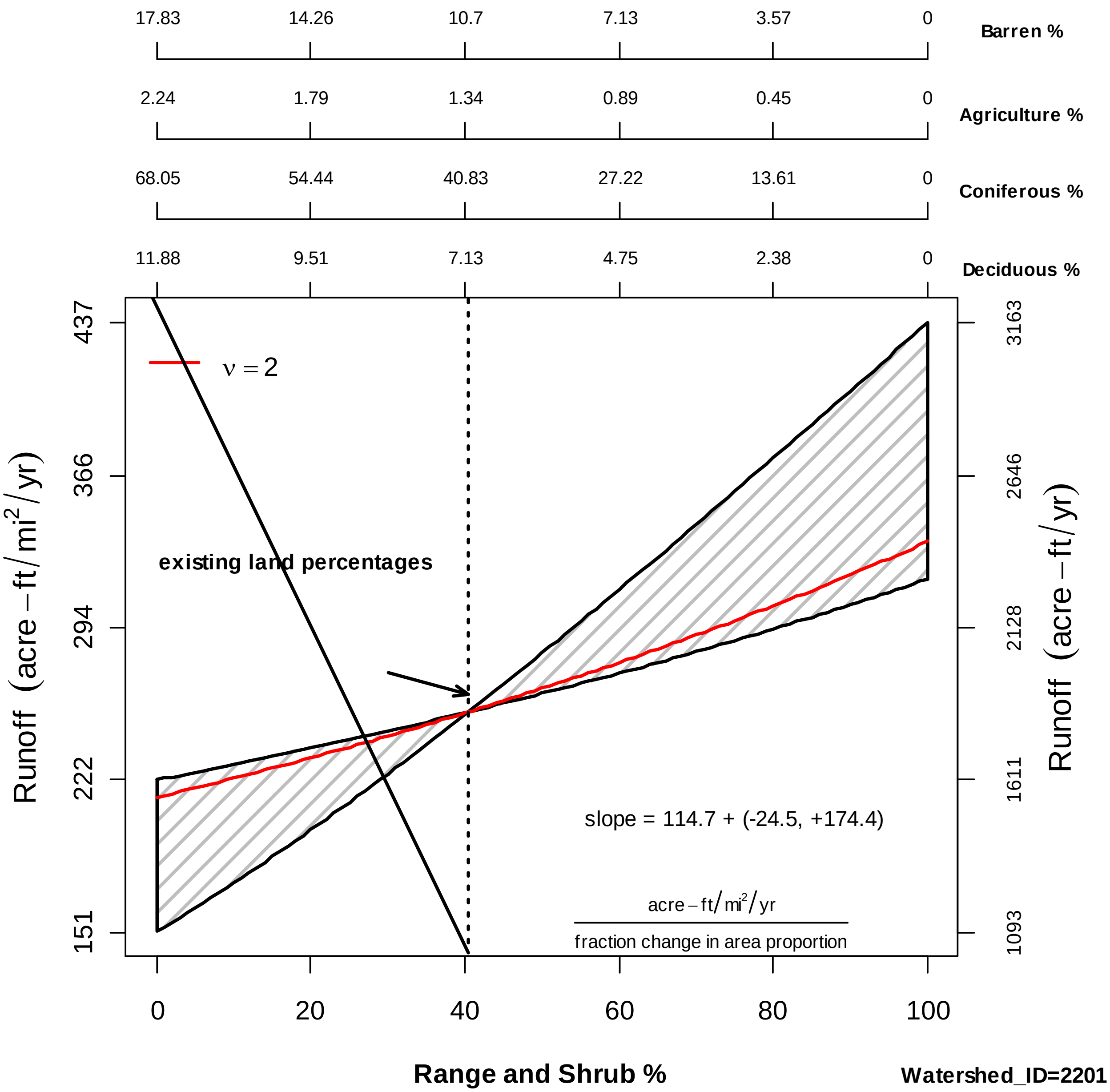

Figure 8.15. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Sevier River near Hatch watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 335.21 mi^2.

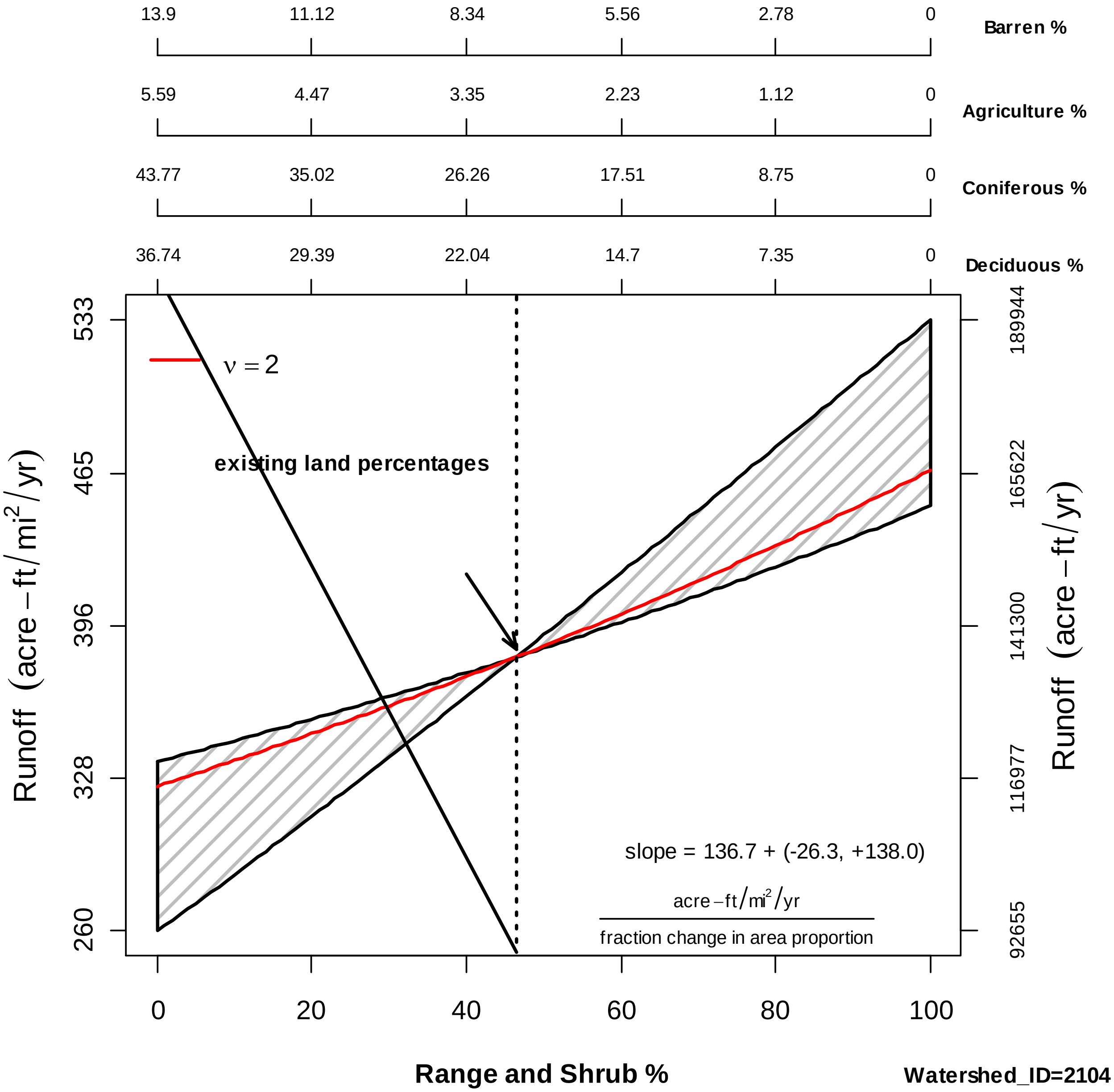

Figure 8.16. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Duchense River near Tabiona watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at ν = 2 with ± bounds from ν = 1.5 to ν = 10. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 356.37 mi^2.

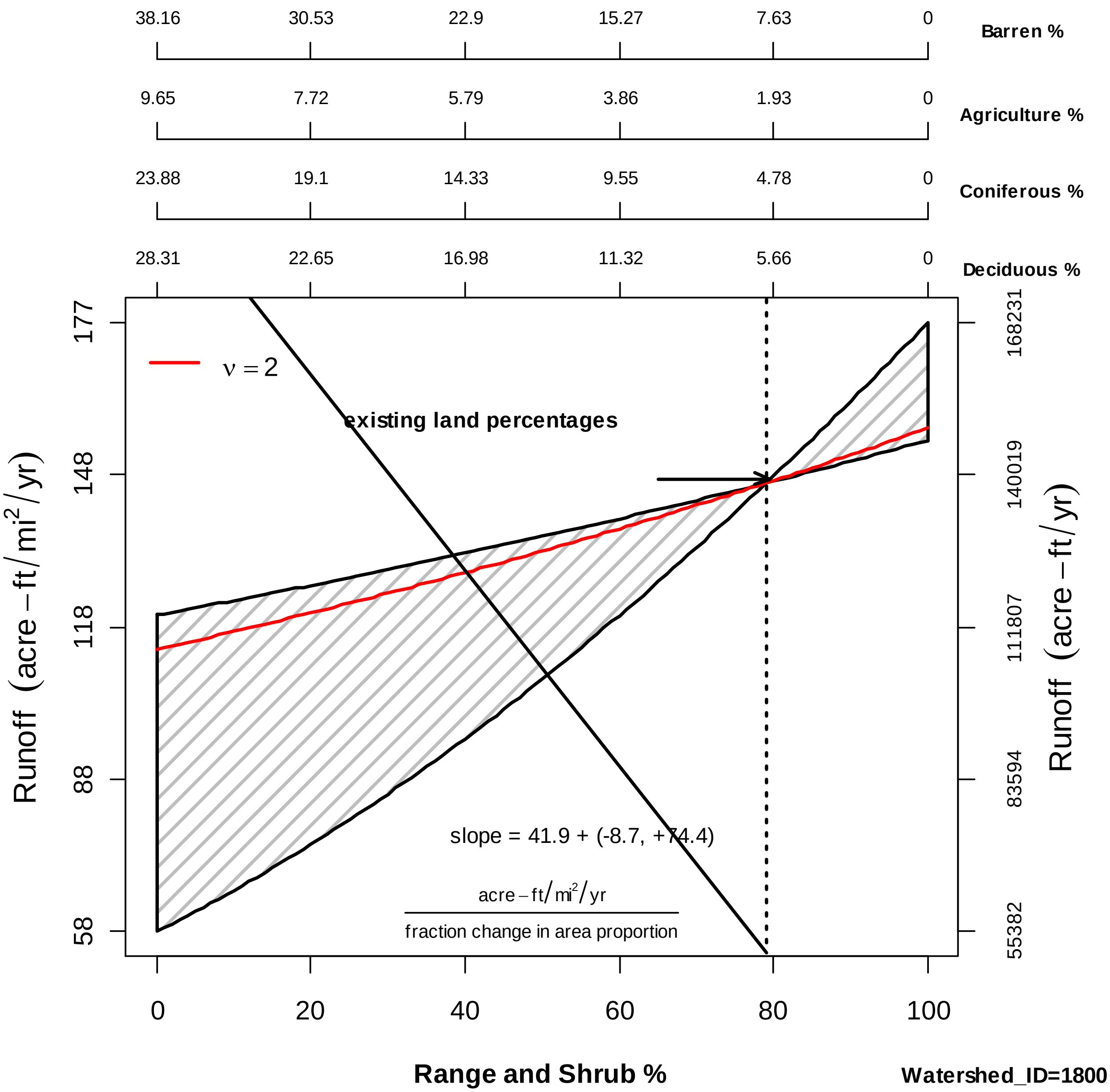

Figure 8.17. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Virgin River near Virgin watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 948.32 mi^2.

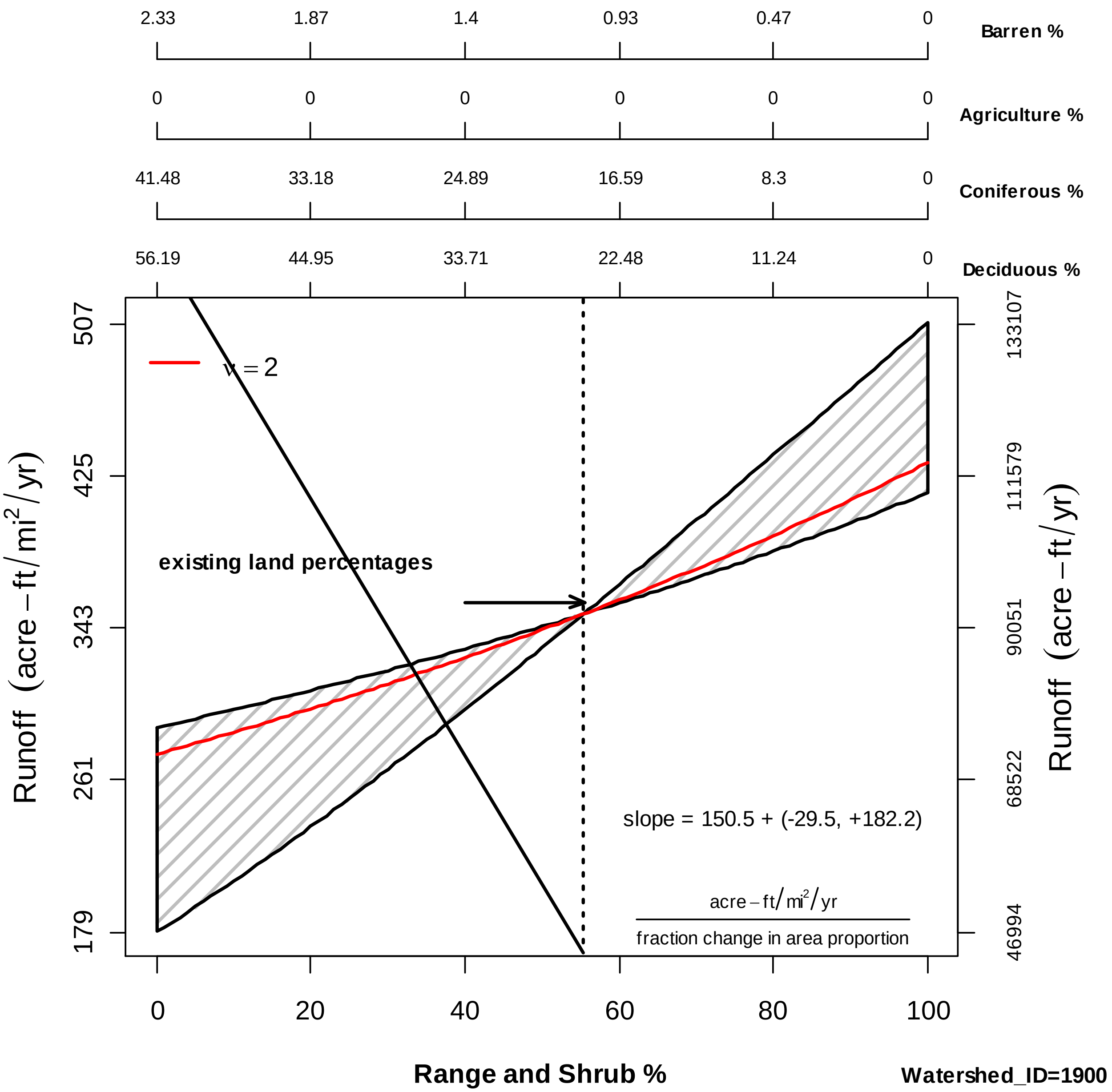

Figure 8.18. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Blacksmith Fork near Hyrum watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 262.54 mi^2.

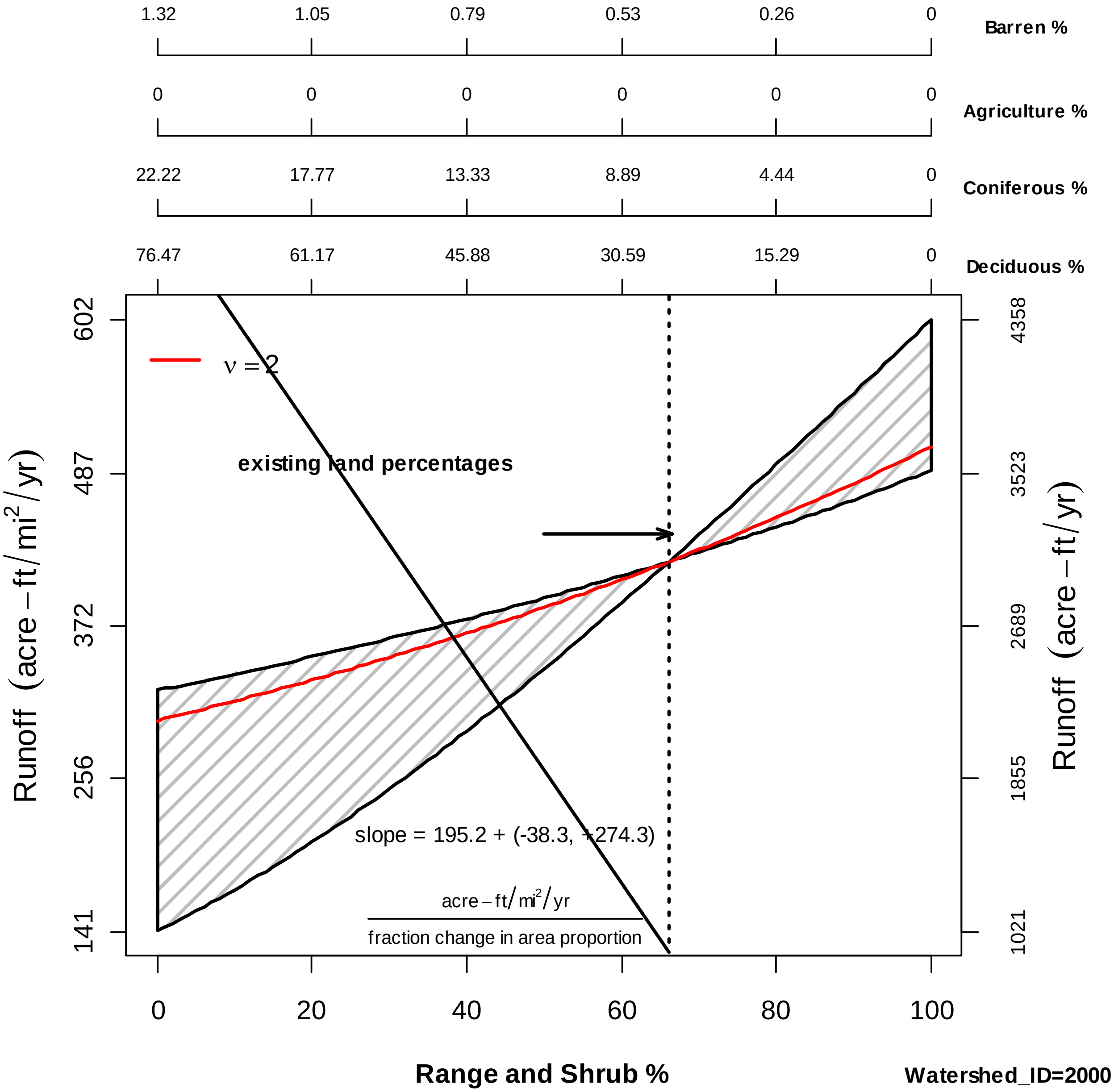

Figure 8.19. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Red Butte creek at Fort Douglas near SLC watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 7.24 mi^2.

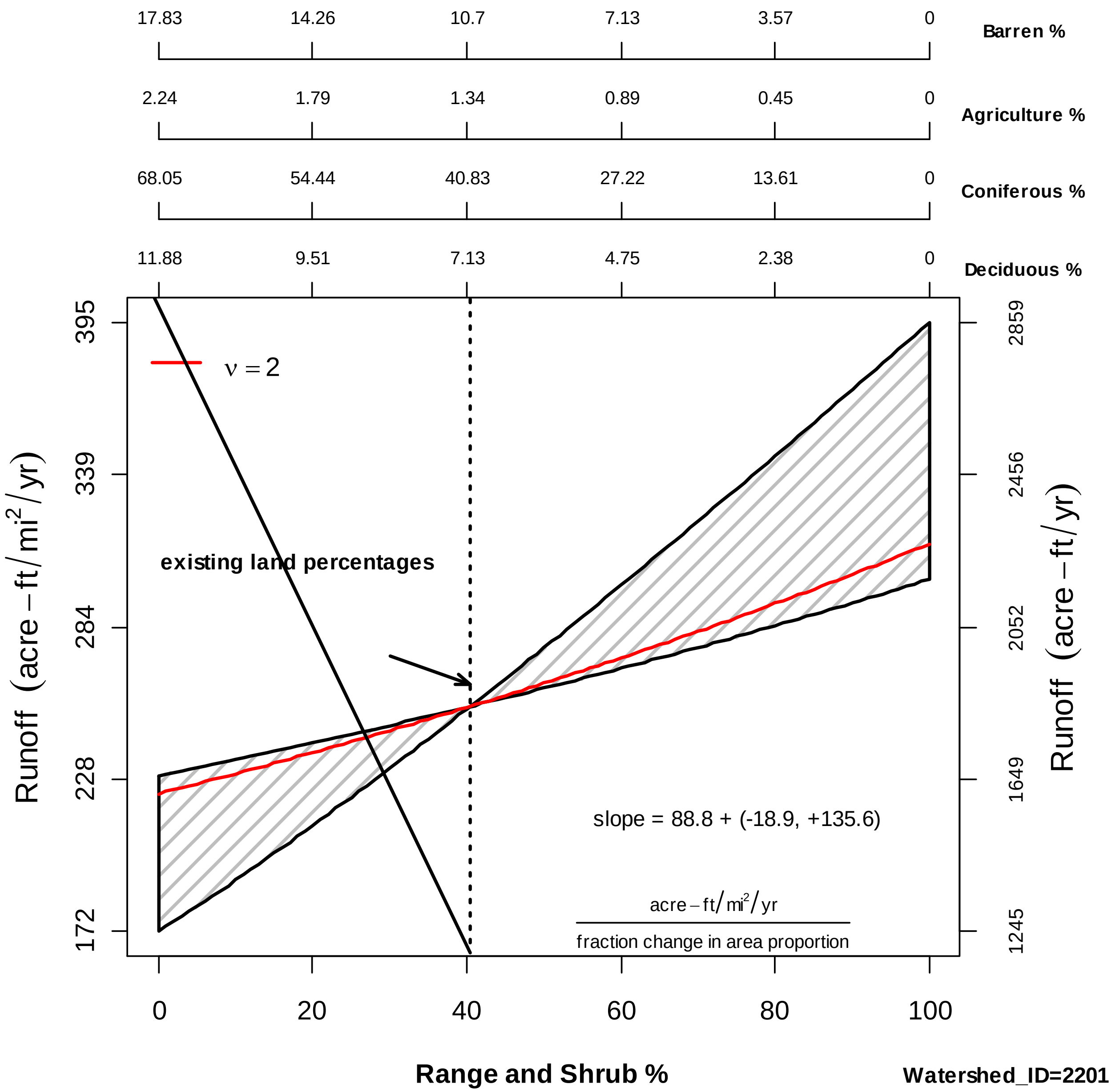

Figure 8.20. Runoff sensitivity to changes in Range/Shrub/Other land cover percentage in the Sevier River near Hatch watershed. Other land cover percentages adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 and Agriculture 1.0. The watershed area is 335.21 mi^2.

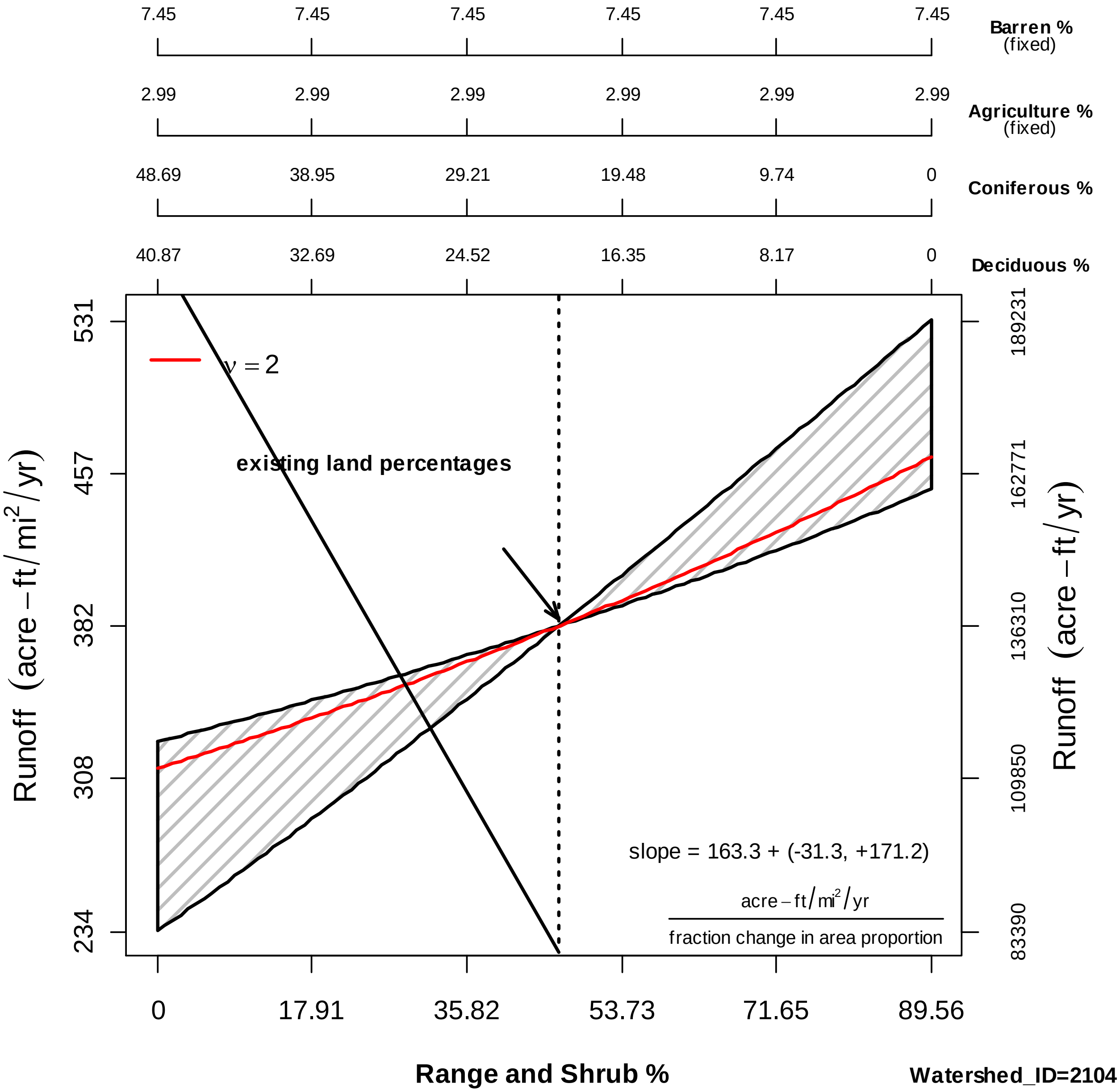

Figure 8.21. Runoff sensitivity to change in Range/Shrub/Other percentage in the Duchense River near Tabiona watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 356.37 mi^2.

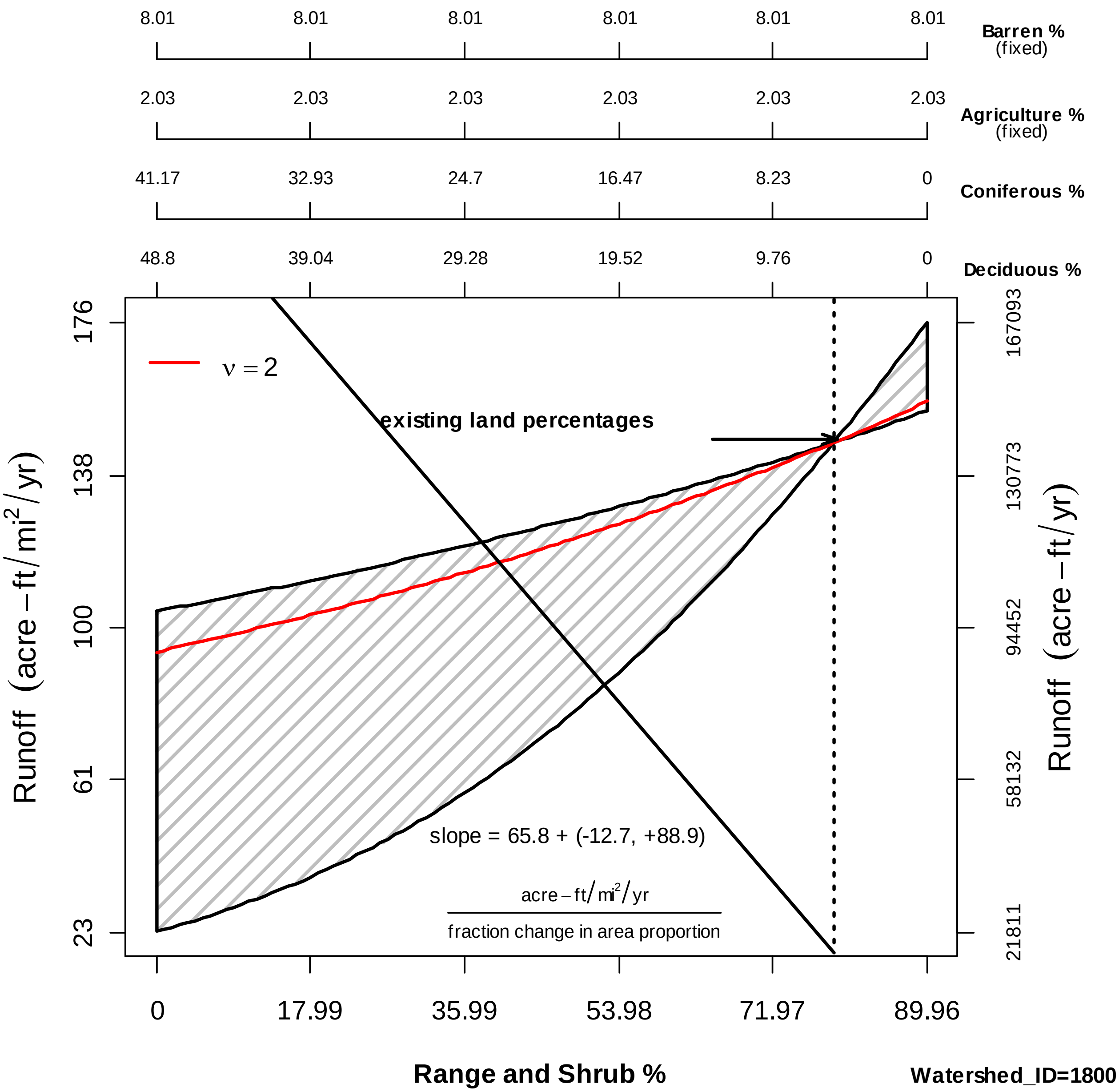

Figure 8.22. Runoff sensitivity to change in Range/Shrub/Other percentage in the Virgin River near Virgin watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 948.32 mi^2.

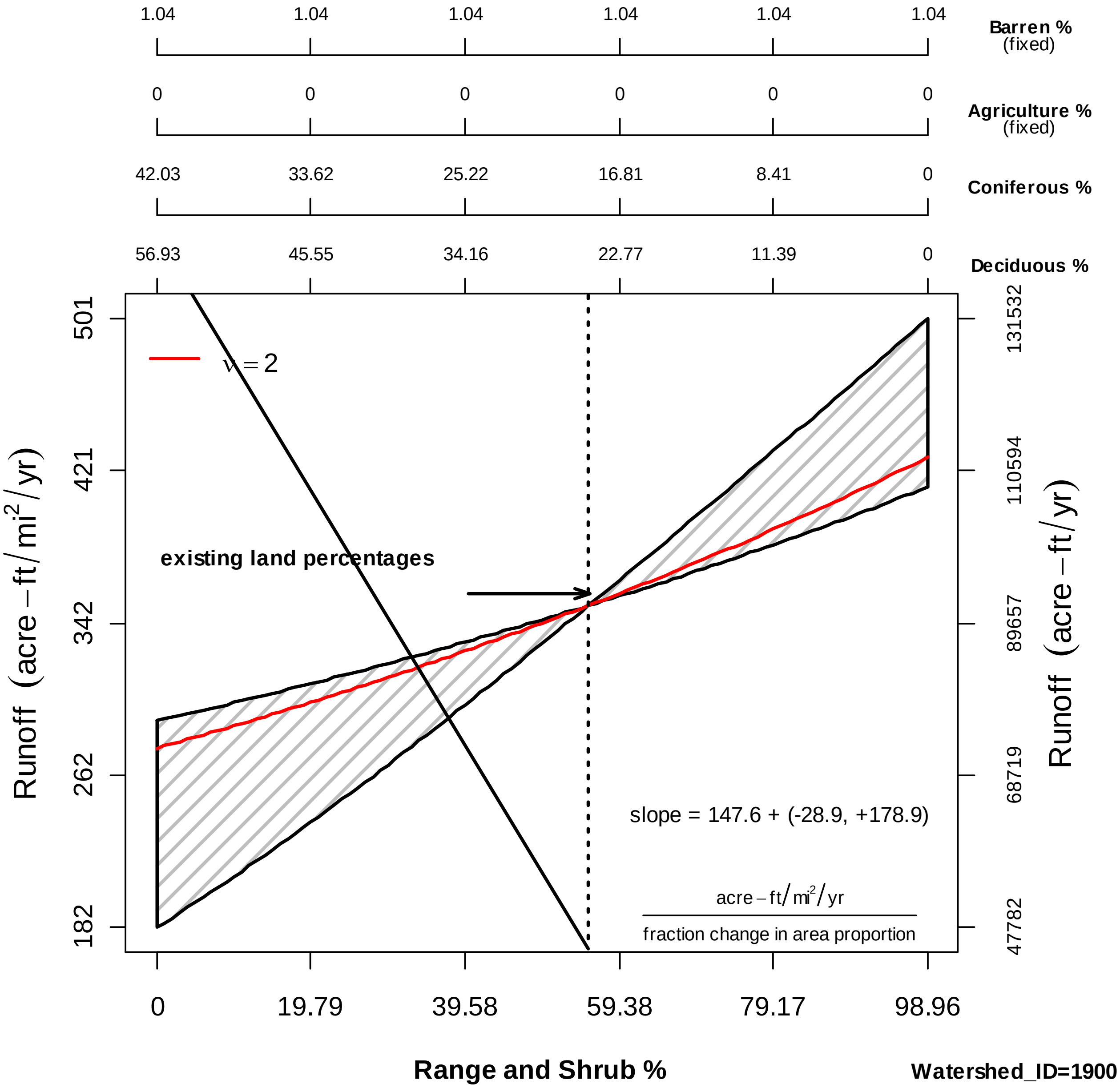

Figure 8.23. Runoff sensitivity to change in Range/Shrub/Other percentage in the Blacksmith Fork near Hyrum watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 262.54 mi^2.

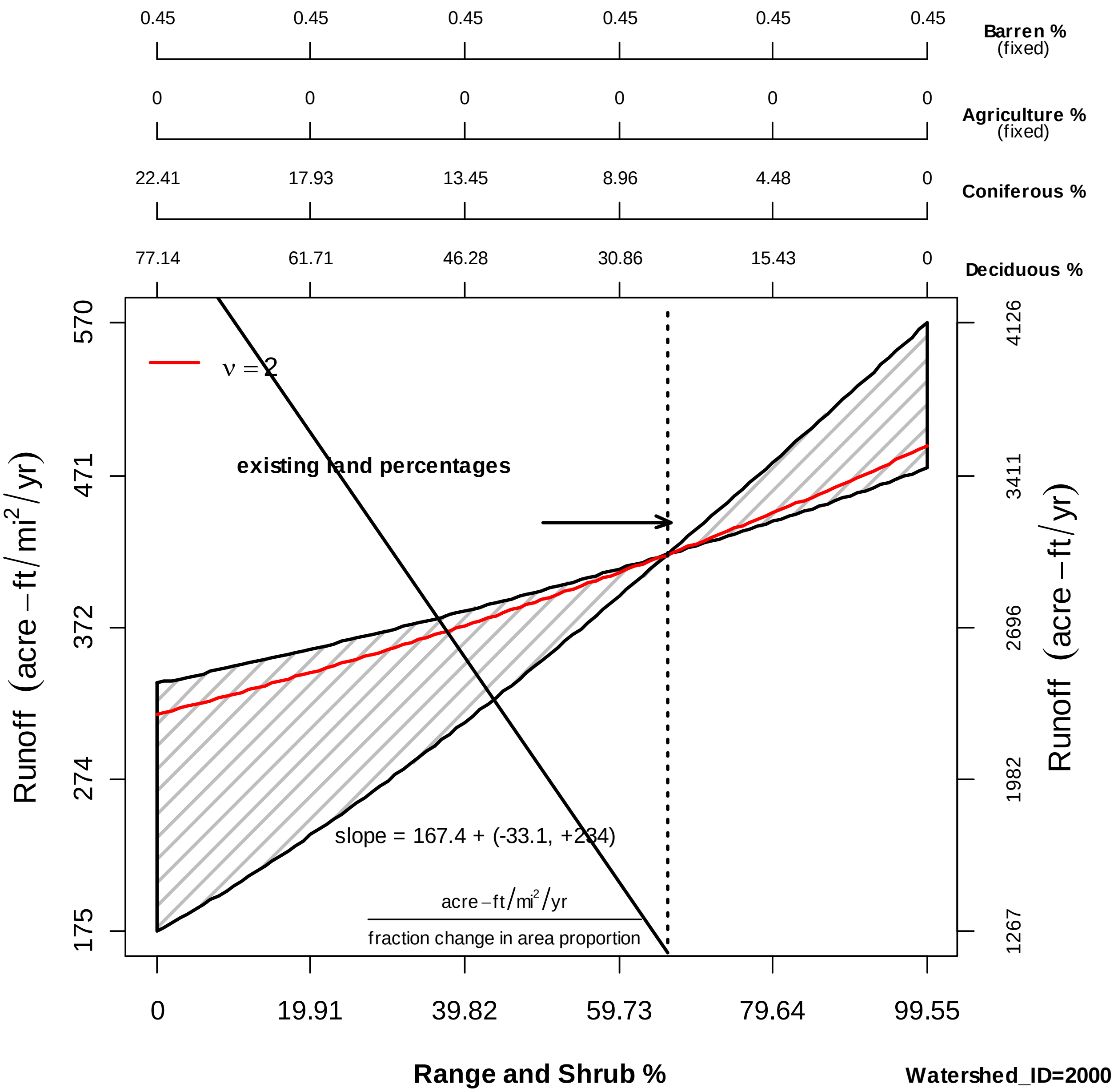

Figure 8.24. Runoff sensitivity to change in Range/Shrub/Other percentage in the Red Butte creek at Fort Douglas near SLC watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 7.24 mi^2.

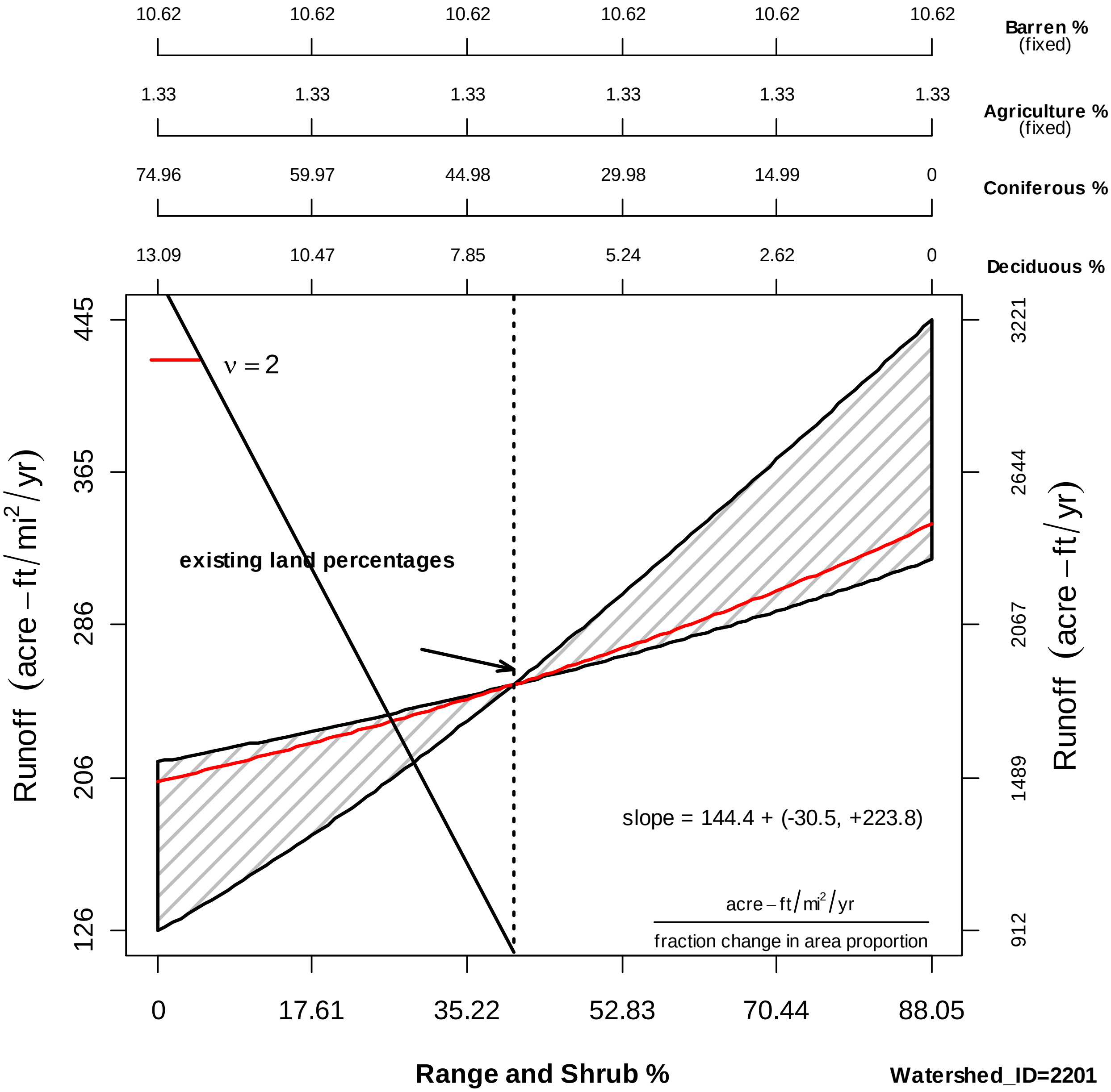

Figure 8.25. Runoff sensitivity to change in Range/Shrub/Other percentage in the Sevier River near Hatch watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.9, Deciduous 0.8, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 335.21 mi^2.

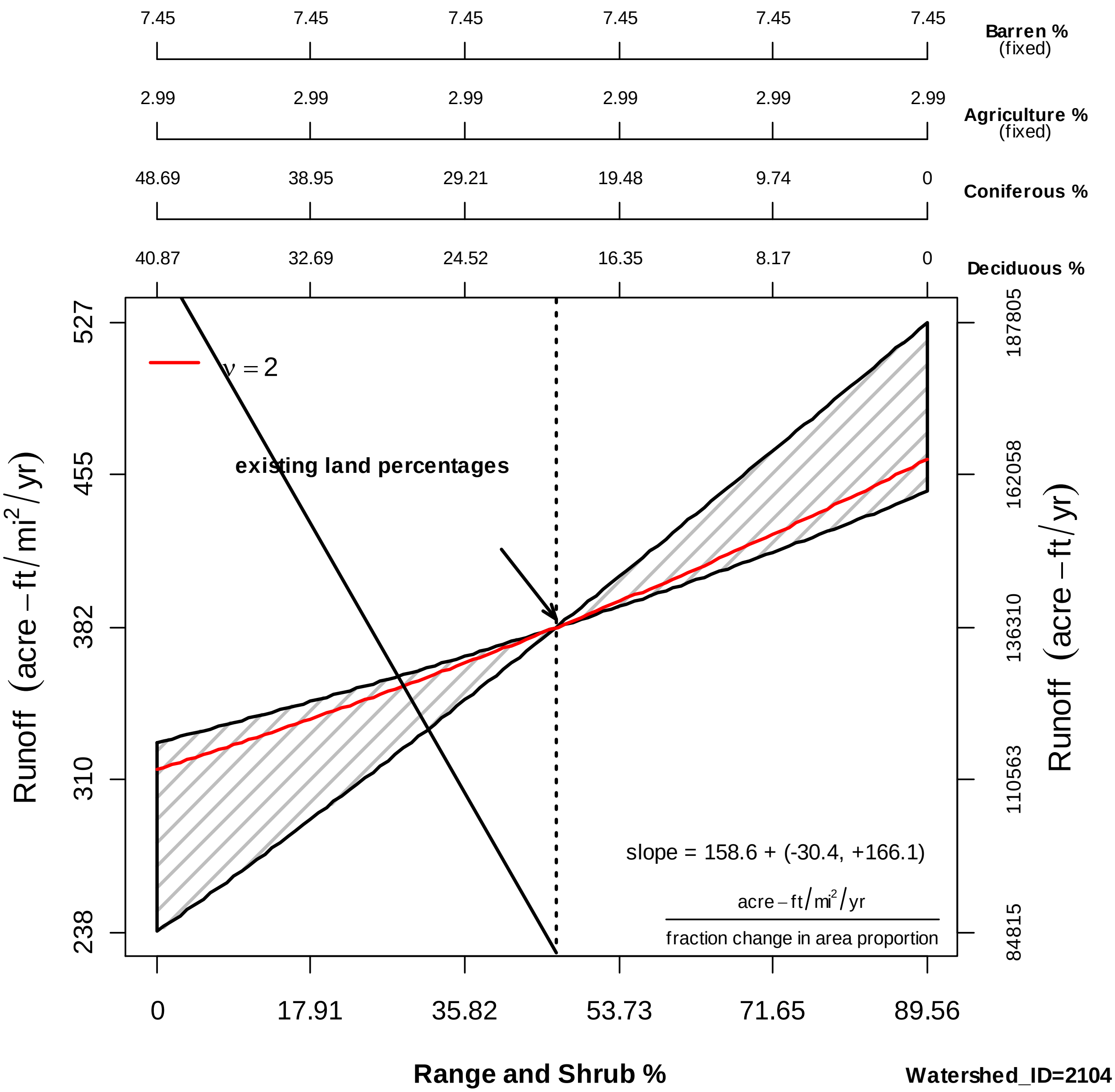

Figure 8.26. Runoff sensitivity to change in Range/Shrub/Other percentage in the Duchense River near Tabiona watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 356.37 mi^2.

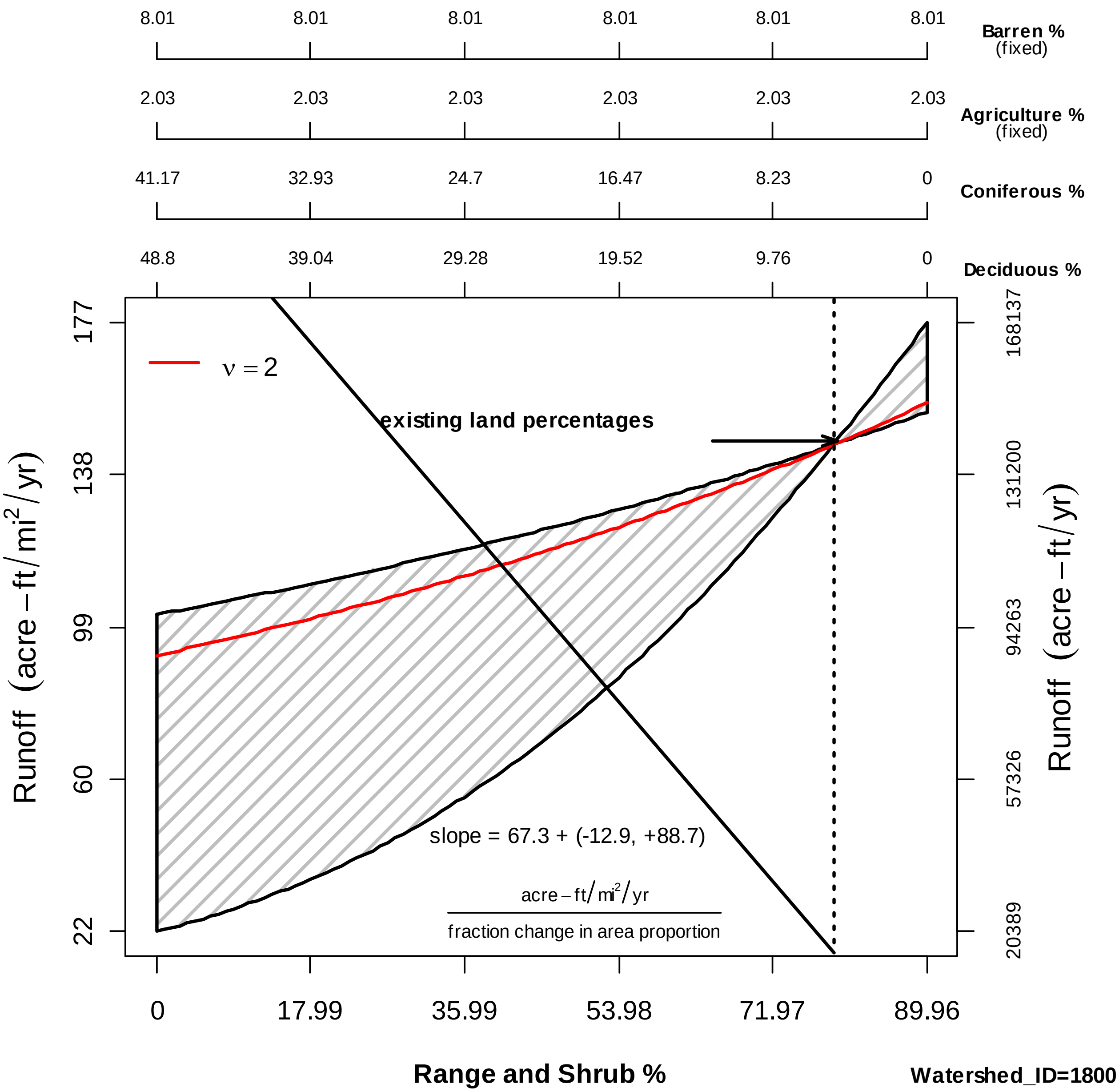

Figure 8.27. Runoff sensitivity to change in Range/Shrub/Other percentage in the Virgin River near Virgin watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $\nu = 2$ with ± bounds from $\nu = 1.5$ to $\nu = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 948.32 mi^2.

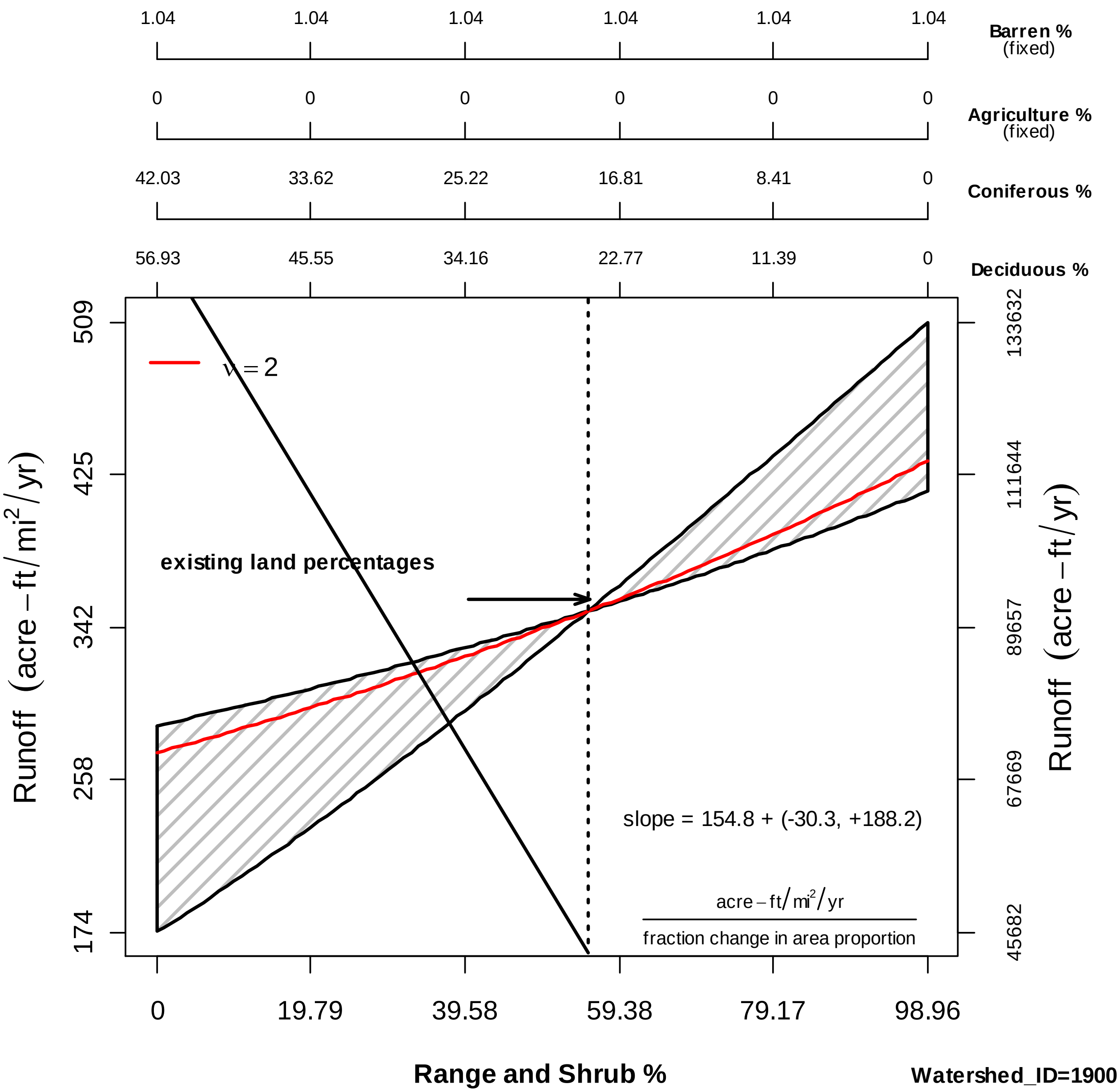

Figure 8.28. *Runoff sensitivity to change in Range/Shrub/Other percentage in the Blacksmith Fork near Hyrum watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at v = 2 with ± bounds from v = 1.5 to v = 10. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 262.54 mi²*.

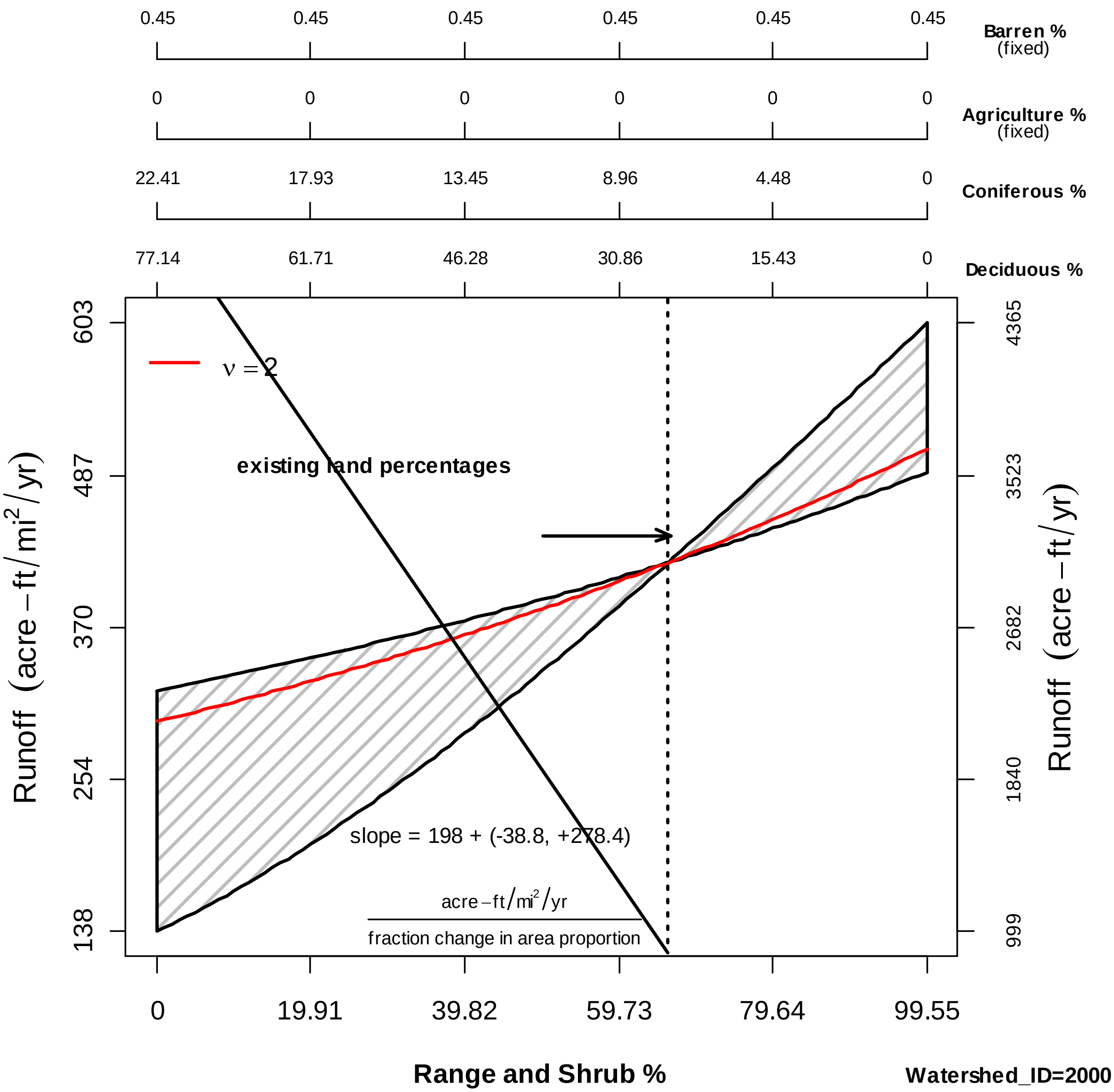

Figure 8.29. *Runoff sensitivity to change in Range/Shrub/Other percentage in the Red Butte creek at Fort Douglas near SLC watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $v = 2$ with ± bounds from $v = 1.5$ to $v = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 7.24 mi^2.*

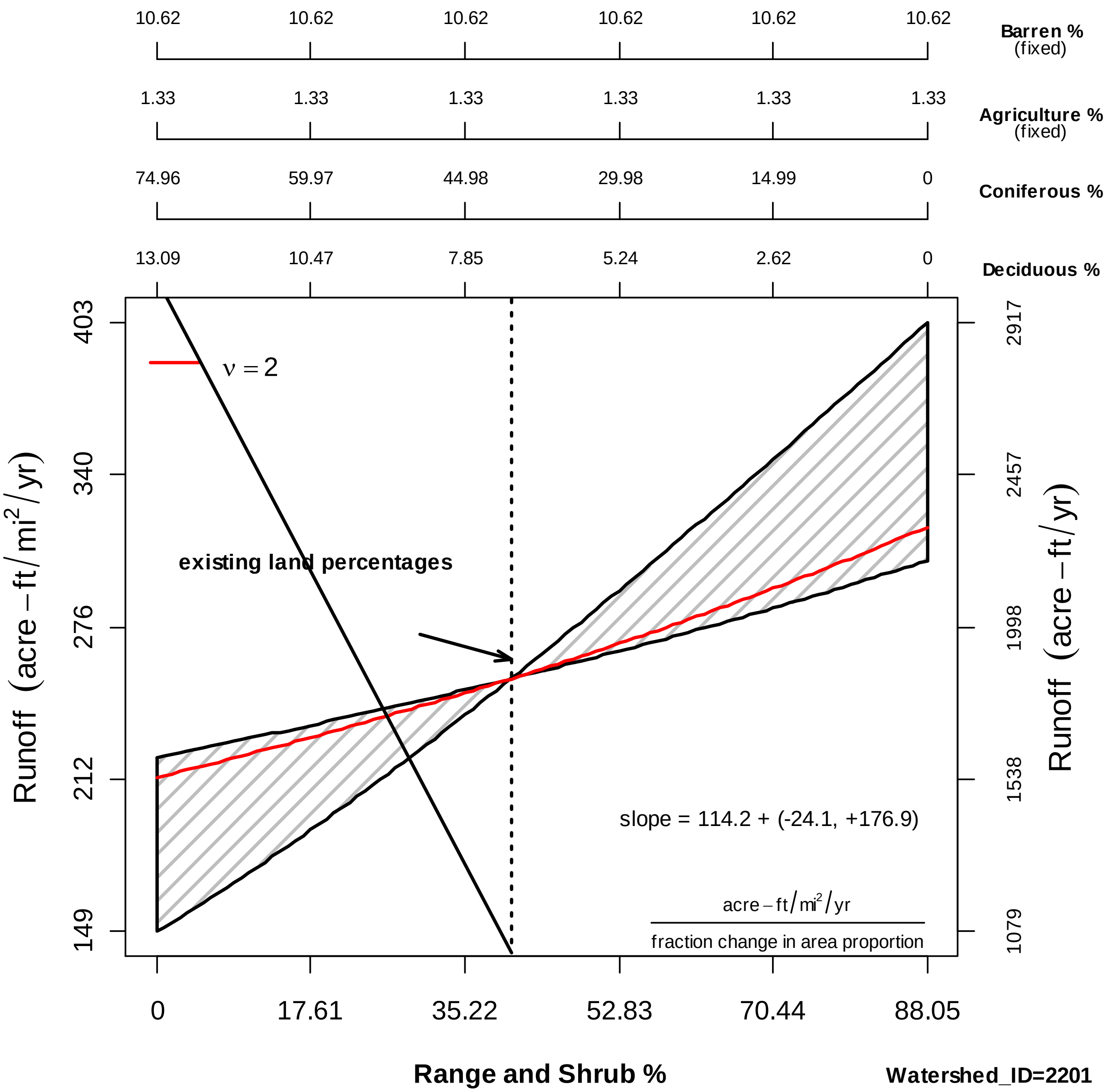

Figure 8.30. *Runoff sensitivity to change in Range/Shrub/Other percentage in the Sevier River near Hatch watershed. The percentages of Agriculture and Barren are held fixed while percentages of Coniferous and Deciduous adjust proportionately. The slope gives the runoff sensitivity at $v = 2$ with ± bounds from $v = 1.5$ to $v = 10$. The relative potential evapotranspiration coefficients are: Coniferous 0.8, Deciduous 0.9, Range/Shrub/Other 0.6, Barren 0.5 (fixed) and Agriculture 1.0 (fixed). The watershed area is 335.21 mi^2.*

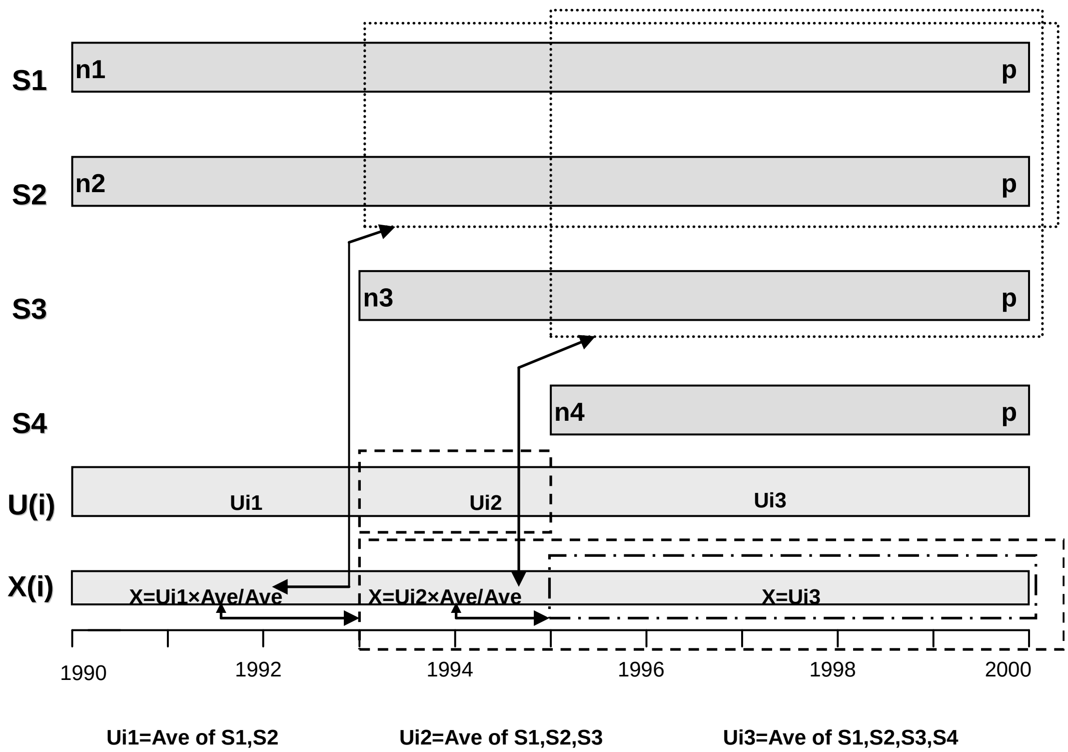

Figure 9. *Illustration of the adjustment procedure used in calculating an average time series of maximum or April's first snow water equivalent (SWE) values in each watershed. Four stations (S1, S2, S3, and S4) with varying length of record over the interval (1990-2000) are used for illustrative purpose.*

Table 1. *USGS gauging stations at the outlet of each study watershed.*

Watershed_ID	USGS #	Station Name	Drainage Area (sq.km)	Drainage Area (sq.mile)
1100	10011500	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	449.40	173.51
1101	10026500	BEAR RIVER NEAR RANDOLPH	4183.50	1615.26
1102	10023000	BIG CREEK NEAR RANDOLPH	131.53	50.78
1200	10136500	WEBER RIVER AT GATEWAY	4219.20	1629.04
1201	10141000	WEBER RIVER NEAR PLAIN CITY	5399.89	2084.91
1202	10137500	SOUTH FORK OGDEN RIVER NEAR HUNTSVILLE	356.85	137.78
1203	10143500	CENTERVILLE CREEK ABV DIV NR CENTERVILLE	8.11	3.13
1204	10140100	OGDEN RIVER BL PINEVIEW RES NR HUNTSVILLE	822.74	317.66
1300	10146000	SALT CREEK AT NEPHI	246.08	95.01
1301	10146400	CURRANT CREEK NEAR MONA	589.62	227.65
1302	10166430	WEST CANYON CREEK NEAR CEDAR FORT	69.56	26.86
1400	09310500	*FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	158.17	61.07
1401	09314500	PRICE RIVER AT WOODSIDE	4546.04	1755.24
1402	09312600	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT	195.26	75.39
1403	09310700	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD	70.73	27.31
1500	09330000	FREMONT RIVER NEAR BICKNELL	1954.71	754.72
1501	09330230	FREMONT RIVER NEAR CAINEVILLE	3136.00	1210.82
1600	10189000	EAST FORK SEVIER RIVER NEAR KINGSTON	3135.27	1210.53
1700	10242000	COAL CREEK NEAR CEDAR CITY	208.03	80.32
1800	09406000	VIRGIN RIVER AT VIRGIN	2456.13	948.32
1801	09409880	SANTA CLARA RIVER AT GUNLOCK	728.80	281.39
1802	09404450	EAST FORK VIRGIN RIVER NEAR GLENDALE	193.53	74.72
1803	09405500	NORTH FORK VIRGIN RIVER NEAR SPRINGDALE	904.76	349.33
1804	09409100	SANTA CLARA RIVER ABV BAKER RES, NR CENTRAL	290.89	112.31
1900	10113500	*BLACKSMITH FORK AB UP and L CO.'S DAM NR HYRUM	679.97	262.54
1901	10109001	COM F LOGAN R AB ST D AND LO HP AND SM C N LO	558.51	215.64
1902	10105900	LITTLE BEAR RIVER AT PARADISE	455.55	175.89
2000	10172200	*RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC	18.75	7.24
2001	10168000	LITTLE COTTONWOOD CREEK @ JORDAN RIVER NR SLC	105.48	40.73
2002	10170490	COM FLW JORDAN RIVER & SURPLUS CANAL @ SLC	8766.42	3384.73
2100	09299500	*WHITEROCKS RIVER NEAR WHITEROCKS	283.35	109.40
2101	09279000	ROCK CREEK NEAR MOUNTAIN HOME	378.04	145.96
2102	09292500	YELLOWSTONE RIVER NEAR ALTONAH	335.18	129.41
2103	09291000	LAKE FORK RIVER BL MOON LAKE NR MOUNTAIN HOME	295.95	114.27
2104	09277500	DUCHESNE RIVER NEAR TABIONA	922.99	356.37
2105	09279150	DUCHESNE RIV ABV KNIGHT DIVERSION, NR DUCHESNE	1612.22	622.48
2200	10183500	SEVIER RIVER NEAR KINGSTON	2926.81	1130.05
2201	10174500	*SEVIER RIVER AT HATCH	868.19	335.21
2202	10173450	MAMMOTH CREEK ABV WEST HATCH DITCH, NEAR HATCH	272.96	105.39

* HCDN station

Table 2. *Runoff ratio (Q/AP) Mann Kendall trend analysis.*

Watershed_ID	Station Name	μ	σ	CV	ρ1	τ (tau)	p-value	Trend
1100	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	0.379	0.065	0.171	0.264	0.0765	0.38705	No Trend
1101	BEAR RIVER NEAR RANDOLPH	0.085	0.049	0.575	0.520	-0.0124	0.90801	No Trend
1102	BIG CREEK NEAR RANDOLPH	0.197	0.113	0.575	0.634	-0.1268	0.24732	No Trend
1200	WEBER RIVER AT GATEWAY	0.173	0.068	0.392	0.584	-0.2019	0.00698	Significant
1201	WEBER RIVER NEAR PLAIN CITY	0.133	0.079	0.594	0.638	-0.3077	0.00002	Highly Significant
1202	SOUTH FORK OGDEN RIVER NEAR HUNTSVILLE	0.365	0.101	0.276	0.262	-0.0714	0.34463	No Trend
1203	CENTERVILLE CREEK ABV DIV NR CENTERVILLE	0.272	0.072	0.265	0.359	0.0319	0.79824	No Trend
1204	OGDEN RIVER BL PINEVIEW RES NR HUNTSVILLE	0.119	0.063	0.527	0.452	0.1429	0.48842	No Trend
1300	SALT CREEK AT NEPHI	0.168	0.072	0.426	0.296	-0.1714	0.12746	No Trend
1301	CURRANT CREEK NEAR MONA	0.087	0.063	0.732	0.774	-0.2867	0.04713	Significant
1302	WEST CANYON CREEK NEAR CEDAR FORT	0.054	0.027	0.499	0.183	-0.1282	0.35900	No Trend
1400	*FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	0.379	0.113	0.299	0.216	-0.0452	0.59853	No Trend
1401	PRICE RIVER AT WOODSIDE	0.060	0.040	0.661	0.483	-0.0340	0.73674	No Trend
1402	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT	0.268	0.126	0.471	0.334	-0.2540	0.03033	Significant
1403	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD	0.259	0.094	0.363	0.519	0.0190	0.92782	No Trend
1500	FREMONT RIVER NEAR BICKNELL	0.092	0.019	0.206	0.338	0.0000	1.00000	No Trend
1501	FREMONT RIVER NEAR CAINEVILLE	0.057	0.012	0.203	0.460	0.1238	0.29427	No Trend
1600	EAST FORK SEVIER RIVER NEAR KINGSTON	0.056	0.020	0.359	0.163	-0.0925	0.20329	No Trend
1700	COAL CREEK NEAR CEDAR CITY	0.182	0.062	0.343	0.051	-0.1083	0.19005	No Trend
1800	VIRGIN RIVER AT VIRGIN	0.143	0.043	0.298	0.385	-0.3272	0.00002	Highly Significant
1801	SANTA CLARA RIVER AT GUNLOCK	0.061	0.038	0.618	0.214	0.0160	0.90560	No Trend
1802	EAST FORK VIRGIN RIVER NEAR GLENDALE	0.190	0.062	0.327	0.404	-0.3544	0.00212	Significant
1803	NORTH FORK VIRGIN RIVER NEAR SPRINGDALE	0.175	0.055	0.314	0.130	-0.1647	0.03438	Significant
1804	SANTA CLARA RIVER ABV BAKER RES, NR CENTRAL	0.035	0.028	0.817	-0.174	-0.0330	0.91281	No Trend
1900	*BLACKSMITH FORK AB UP and L CO.'S DAM NR HYRUM	0.255	0.080	0.313	0.471	-0.1031	0.16868	No Trend
1901	COM F LOGAN R AB ST D AND LO HP AND SM C N LO	0.399	0.083	0.208	0.230	-0.0443	0.55878	No Trend
1902	LITTLE BEAR RIVER AT PARADISE	0.196	0.072	0.367	0.625	-0.1636	0.53342	No Trend
2000	*RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC	0.209	0.085	0.408	0.496	-0.0949	0.39503	No Trend
2001	LITTLE COTTONWOOD CREEK @ JORDAN RIVER NR SLC	0.305	0.133	0.437	0.801	-0.4505	0.02854	Significant
2002	COM FLW JORDAN RIVER & SURPLUS CANAL @ SLC	0.099	0.061	0.618	0.743	0.4215	0.00000	Highly Significant
2100	*WHITEROCKS RIVER NEAR WHITEROCKS	0.489	0.104	0.214	0.058	-0.1411	0.07211	No Trend
2101	ROCK CREEK NEAR MOUNTAIN HOME	0.450	0.144	0.320	0.637	-0.3082	0.00026	Highly Significant
2102	YELLOWSTONE RIVER NEAR ALTONAH	0.566	0.101	0.179	0.252	0.0076	0.93745	No Trend
2103	LAKE FORK RIVER BL MOON LAKE NR MOUNTAIN HOME	0.564	0.114	0.202	0.011	0.0240	0.78902	No Trend
2104	DUCHESNE RIVER NEAR TABIONA	0.276	0.077	0.281	0.609	-0.3737	0.00000	Highly Significant
2105	DUCHESNE RIV ABV KNIGHT DIVERSION, NR DUCHESNE	0.266	0.096	0.361	0.607	-0.3788	0.00205	Significant
2200	SEVIER RIVER NEAR KINGSTON	0.079	0.033	0.419	0.549	-0.2132	0.00331	Significant
2201	*SEVIER RIVER AT HATCH	0.185	0.071	0.385	0.531	-0.3178	0.00004	Highly Significant
2202	MAMMOTH CREEK ABV WEST HATCH DITCH, NEAR HATCH	0.172	0.068	0.393	0.342	-0.2605	0.02020	Significant

* HCDN station

Table 2. *Key variables explanations*

μ: arithmetic mean

σ: unbiased standard deviation

CV: coefficient of variation (σ/μ)

ρ_1: Lag 1 autocorrelation

τ (tau): Kendall's tau correlation coefficient

p-value: 2 sided-test

Trend: $p \leq 0.05$ Significant; $p \leq 0.001$ Highly Significant

Table 3. *Watershed Land Cover classification using the GAP (1995) & the SWReGAP (2004) datasets.*

Watershed_ID	Station Name	Land Cover (Area %) Agriculture	Barren	Conifer Forest	Deciduous Forest	Range, Shrub, Others	Year
1100	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	0.08	11.84	51.40	18.92	17.76	1995
		0.06	16.49	43.02	14.36	26.07	2004
1101	BEAR RIVER NEAR RANDOLPH	9.90	2.21	12.54	10.43	64.92	1995
		9.33	3.45	10.93	8.24	68.05	2004
1102	BIG CREEK NEAR RANDOLPH	0.01	0.00	6.66	12.01	81.31	1995
		0.07	0.11	9.76	7.76	82.29	2004
1200	WEBER RIVER AT GATEWAY	4.44	0.71	7.68	18.10	69.07	1995
		4.61	2.29	8.53	21.43	63.14	2004
1201	WEBER RIVER NEAR PLAIN CITY	5.32	0.71	6.80	17.44	69.73	1995
		5.61	2.20	8.19	22.64	61.36	2004
1202	SOUTH FORK OGDEN RIVER NEAR HUNTSVILLE	0.18	0.13	6.94	25.45	67.30	1995
		0.17	0.78	9.81	37.99	51.25	2004
1203	CENTERVILLE CREEK ABV DIV NR CENTERVILLE	0.00	0.77	12.18	24.28	62.77	1995
		0.00	0.23	17.28	27.47	55.02	2004
1204	OGDEN RIVER BL PINEVIEW RES NR HUNTSVILLE	4.56	0.38	3.96	18.75	72.35	1995
		5.72	1.36	6.97	34.39	51.57	2004
1300	SALT CREEK AT NEPHI	0.00	3.10	6.81	13.22	76.87	1995
		1.09	3.79	6.26	14.33	74.52	2004
1301	CURRANT CREEK NEAR MONA	13.83	1.73	6.13	7.78	70.53	1995
		17.79	2.75	6.07	8.59	64.80	2004
1302	WEST CANYON CREEK NEAR CEDAR FORT	0.00	0.00	16.58	12.12	71.30	1995
		0.00	1.30	12.52	17.23	68.95	2004
1400	*FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	0.00	0.06	9.71	35.57	54.67	1995
		0.00	0.03	8.60	50.63	40.74	2004
1401	PRICE RIVER AT WOODSIDE	2.05	0.85	9.49	6.82	80.79	1995
		2.76	6.97	6.56	9.44	74.27	2004
1402	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT	0.00	0.22	22.68	21.85	55.25	1995
		0.00	2.56	19.53	21.96	55.94	2004
1403	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD	0.00	0.59	29.57	39.48	30.36	1995
		0.52	0.14	29.76	47.29	22.29	2004
1500	FREMONT RIVER NEAR BICKNELL	3.43	2.42	34.44	4.82	54.90	1995
		3.21	3.69	11.78	9.55	71.77	2004
1501	FREMONT RIVER NEAR CAINEVILLE	2.67	5.79	28.71	3.80	59.02	1995
		2.62	15.42	12.30	7.47	62.19	2004
1600	EAST FORK SEVIER RIVER NEAR KINGSTON	2.28	1.97	31.29	4.21	60.26	1995
		2.62	3.00	22.42	10.15	61.82	2004
1700	COAL CREEK NEAR CEDAR CITY	0.00	8.83	24.22	8.15	58.80	1995
		0.00	10.59	24.26	30.18	34.97	2004

* HCDN station

Table 3. *Continued*

Watershed_ID	Station Name	Land Cover (Area %)					Year
		Agriculture	Barren	Conifer Forest	Deciduous Forest	Range, Shrub, Other	
1800	VIRGIN RIVER AT VIRGIN	1.41	4.09	4.27	2.69	87.53	1995
		2.03	8.01	5.01	5.94	79.01	2004
1801	SANTA CLARA RIVER AT GUNLOCK	2.04	0.15	9.32	1.14	87.35	1995
		0.62	0.70	10.23	3.12	85.33	2004
1802	EAST FORK VIRGIN RIVER NEAR GLENDALE	1.21	1.13	15.46	2.47	79.73	1995
		2.26	3.20	17.02	0.76	76.75	2004
1803	NORTH FORK VIRGIN RIVER NEAR SPRINGDALE	1.23	4.57	7.29	6.28	80.62	1995
		0.90	5.65	8.38	15.37	69.69	2004
1804	SANTA CLARA RIVER ABV BAKER RES, NR CENTRAL	3.17	0.25	22.85	2.84	70.89	1995
		1.50	0.41	25.57	7.06	65.45	2004
1900	*BLACKSMITH FORK AB UP and L CO.'S DAM NR HYRUM	0.16	0.16	12.38	37.36	49.94	1995
		0.00	1.04	18.51	25.08	55.37	2004
1901	COM F LOGAN R AB ST D AND LO HP AND SM C N LO	0.00	0.65	17.53	41.28	40.54	1995
		0.00	3.55	27.94	26.07	42.45	2004
1902	LITTLE BEAR RIVER AT PARADISE	3.73	0.16	5.09	43.18	47.84	1995
		2.45	1.05	10.65	34.44	51.42	2004
2000	*RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC	0.00	0.00	6.11	18.38	75.52	1995
		0.00	0.45	7.53	25.92	66.10	2004
2001	LITTLE COTTONWOOD CREEK @ JORDAN RIVER NR SLC	0.68	12.50	28.13	9.83	48.86	1995
		0.67	28.25	21.93	8.39	40.76	2004
2002	COM FLW JORDAN RIVER & SURPLUS CANAL @ SLC	12.11	1.12	8.31	11.77	66.69	1995
		13.24	3.32	8.05	12.77	62.62	2004
2100	*WHITEROCKS RIVER NEAR WHITEROCKS	0.00	22.53	68.76	1.51	7.20	1995
		0.00	31.38	51.42	3.08	14.12	2004
2101	ROCK CREEK NEAR MOUNTAIN HOME	0.00	22.25	65.32	2.94	9.49	1995
		0.05	23.74	56.43	5.48	14.30	2004
2102	YELLOWSTONE RIVER NEAR ALTONAH	0.00	32.83	58.37	2.11	6.70	1995
		0.15	36.16	46.91	5.01	11.78	2004
2103	LAKE FORK RIVER BL MOON LAKE NR MOUNTAIN HOME	0.00	32.85	60.99	1.65	4.51	1995
		0.00	32.52	54.04	2.98	10.46	2004
2104	DUCHESNE RIVER NEAR TABIONA	3.93	5.75	27.79	19.39	43.14	1995
		2.99	7.45	23.46	19.69	46.41	2004
2105	DUCHESNE RIV ABV KNIGHT DIVERSION, NR DUCHESNE	2.80	8.85	33.51	13.70	41.14	1995
		2.09	10.15	28.40	15.04	44.31	2004
2200	SEVIER RIVER NEAR KINGSTON	3.28	2.32	30.48	1.20	62.71	1995
		3.72	6.53	22.90	4.90	61.94	2004
2201	*SEVIER RIVER AT HATCH	1.02	4.22	41.78	1.64	51.34	1995
		1.33	10.62	40.54	7.08	40.44	2004
2202	MAMMOTH CREEK ABV WEST HATCH DITCH, NEAR HATCH	0.00	7.74	53.33	2.34	36.60	1995
		0.61	17.74	43.34	13.67	24.64	2004

* HCDN station

Table 4. *Water related land use from Utah Division of Water Resources.*

Watershed ID	Watershed Name	A_{total} (km^2)	IR				NI				RES				RIP				URB				WATER			
			A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}
1100	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	449.40	0.14	0.24	0.20	0.20	0.00	0.00	0.80	0.80	0.70	1.11	0.00	1.11	0.92	2.26	0.41	0.41	0.00	0.01	0.05	0.05	1.17	2.73	3.30	3.31
1101	BEAR RIVER NEAR RANDOLPH, UTAH	4,183.50	244.42	253.93	251.52	250.15	1.23	4.34	52.89	52.89	5.77	7.21	0.00	14.02	14.88	20.26	24.49	24.48	0.50	0.89	1.96	1.96	7.11	7.92	14.49	14.50
1102	BIG CREEK NEAR RANDOLPH	131.53	0.00	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
			A_{88}	A_{99}	A_{03}	A_{06}	A_{88}	A_{99}	A_{03}	A_{06}	A_{88}	A_{99}	A_{03}	A_{06}	A_{88}	A_{99}	A_{03}	A_{06}	A_{88}	A_{99}	A_{03}	A_{06}	A_{88}	A_{99}	A_{03}	A_{06}
1200	WEBER RIVER AT GATEWAY	4,219.20	162.94	162.92	156.78	157.68	15.53	31.70	61.02	61.33	33.07	53.39	104.52	104.61	17.24	13.52	6.96	6.97	5.56	10.44	14.65	14.69	18.87	8.45	22.71	22.76
1201	WEBER RIVER NEAR PLAIN CITY	5,399.89	254.69	255.04	230.58	231.48	19.68	49.95	84.23	84.54	114.81	149.10	201.39	201.48	22.06	20.91	17.95	17.96	47.57	56.79	76.50	76.54	33.17	18.91	36.01	36.07
1202	SOUTH FORK OGDEN RIVER NEAR HUNTSVILLE	356.85	0.59	0.60	0.30	0.30	0.00	0.00	0.19	0.19	2.44	1.46	1.75	1.75	1.13	0.39	0.18	0.18	0.26	0.62	0.74	0.74	0.66	0.00	0.73	0.73
1203	CENTERVILLE CREEK ABV DIV NR CENTERVILLE	8.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1204	OGDEN RIVER BL PINEVIEW RES NR HUNTSVILLE	822.74	35.70	40.25	31.93	31.93	0.34	6.99	11.77	11.77	9.75	12.40	16.50	16.50	3.39	2.36	4.22	4.22	2.34	3.45	3.71	3.71	11.22	9.99	11.24	11.25
			A_{88}	A_{95}	A_{03}	A_{06}	A_{88}	A_{95}	A_{03}	A_{06}	A_{88}	A_{95}	A_{03}	A_{06}	A_{88}	A_{95}	A_{03}	A_{06}	A_{88}	A_{95}	A_{03}	A_{06}	A_{88}	A_{95}	A_{03}	A_{06}
1300	SALT CREEK AT NEPHI	246.08	0.00	0.94	0.74	0.77	0.00	1.64	3.40	3.40	0.00	0.02	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.10	0.02	0.02	0.00	0.01	0.00	0.00
1301	CURRANT CREEK NEAR MONA	589.62	24.40	52.24	43.99	44.02	16.49	52.30	71.18	71.18	0.51	5.81	6.18	6.18	0.00	2.36	0.71	0.71	0.49	1.87	6.36	6.35	0.00	0.15	0.50	0.50
1302	WEST CANYON CREEK NEAR CEDAR FORT	69.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
				A_{91}	A_{99}	A_{06}		A_{91}	A_{99}	A_{06}		A_{91}	A_{99}	A_{06}		A_{91}	A_{99}	A_{06}		A_{91}	A_{99}	A_{06}		A_{91}	A_{99}	A_{06}
1400	*FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	158.17		0.00	0.00	0.00		0.08	0.00	0.00		0.00	3.32	0.00		0.00	0.36	0.00		0.00	0.07	0.00		0.83	1.01	1.15
1401	PRICE RIVER AT WOODSIDE	4,546.04		89.49	97.47	98.85		20.46	15.49	25.76		25.93	32.74	30.45		13.01	26.18	23.82		10.99	12.81	22.89		14.05	13.76	19.11
1402	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT	195.26		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.08	0.06		0.00	0.06	0.00		0.00	0.00	0.03		0.00	0.00	0.00
1403	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD	70.73		0.55	0.34	0.45		0.02	0.00	0.00		0.21	0.28	0.07		0.00	0.07	0.09		0.45	0.35	0.07		0.00	0.00	0.00
			A_{91}	A_{99}	A_{05}	A_{06}	A_{91}	A_{99}	A_{05}	A_{06}	A_{91}	A_{99}	A_{05}	A_{06}	A_{91}	A_{99}	A_{05}	A_{06}	A_{91}	A_{99}	A_{05}	A_{06}	A_{91}	A_{99}	A_{05}	A_{06}
1500	FREMONT RIVER NEAR BICKNELL	1,954.71	64.31	59.16	62.90	62.90	0.65	2.43	2.76	2.76	6.10	5.73	6.03	6.03	3.17	5.97	0.14	0.14	0.61	0.90	2.77	2.77	13.87	14.72	15.01	15.01
1501	FREMONT RIVER NEAR CAINEVILLE	3,136.00	78.89	73.40	78.11	78.11	1.62	5.91	3.98	3.98	8.17	7.01	8.95	8.95	5.12	10.80	1.83	1.83	0.91	1.41	3.60	3.60	14.68	15.51	19.04	19.04
			A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}
1600	EAST FORK SEVIER RIVER NEAR KINGSTON	3,135.27	67.73	70.07	81.36	81.36	1.07	8.27	42.37	42.37	1.81	2.69	2.62	2.62	4.51	1.38	4.31	4.31	0.14	0.30	3.52	3.52	13.61	12.89	14.02	14.02
			A_{89}		A_{01}	A_{06}	A_{89}		A_{01}	A_{06}	A_{89}		A_{01}	A_{06}	A_{89}		A_{01}	A_{06}	A_{89}		A_{01}	A_{06}	A_{89}		A_{01}	A_{06}
1700	COAL CREEK NEAR CEDAR CITY	208.03	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.25		0.01	0.01	0.00		0.00	0.00	0.00		0.04	0.04

* HCDN station

Table 4. *Continued*

Watershed ID	Watershed Name	A_{total} (km^2)	IR				NI				RES				RIP				URB				WATER			
				A_{91}	A_{01}	A_{06}		A_{91}	A_{01}	A_{06}		A_{91}	A_{01}	A_{06}		A_{91}	A_{01}	A_{06}		A_{91}	A_{01}	A_{06}		A_{91}	A_{01}	A_{06}
1800	VIRGIN RIVER AT VIRGIN	2,456.13		14.45	17.47	17.47		35.94	28.65	29.68		5.00	8.11	8.14		4.23	17.93	4.40		0.81	1.82	1.82		1.31	3.26	3.50
1801	SANTA CLARA RIVER AT GUNLOCK	728.80		9.47	15.05	15.05		6.28	3.44	3.44		4.28	8.43	8.43		1.36	1.82	0.18		0.24	0.07	0.07		0.37	0.40	0.40
1802	EAST FORK VIRGIN RIVER NEAR GLENDALE	193.53		1.34	4.14	4.14		2.90	0.00	0.00		0.07	0.30	0.33		0.31	2.49	1.20		0.03	0.14	0.14		0.18	0.23	0.23
1803	NORTH FORK VIRGIN RIVER NEAR SPRINGDALE	904.76		4.29	4.29	4.29		5.85	1.22	1.22		1.57	3.90	3.90		0.17	2.82	1.23		0.11	0.41	0.41		0.93	1.74	1.74
1804	SANTA CLARA RIVER ABV BAKER RES, NR CENTRAL	290.89		5.92	10.77	10.76		3.02	1.50	1.50		2.77	4.27	4.27		0.75	0.99	0.08		0.05	0.02	0.02		0.11	0.11	0.11
			A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}	A_{86}	A_{96}	A_{03}	A_{06}
1900	BLACKSMITH FORK AB UP and L CO.'S DAM NR HYRU	679.97	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.35	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.01	0.24	0.24
1901	COM F LOGAN R AB ST D AND LO HP AND SM C N LO	558.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.52	0.00	0.00	0.04	0.04	0.00	1.45	1.74	1.74	0.08	0.20	0.28	0.28
1902	LITTLE BEAR RIVER AT PARADISE	455.55	7.90	7.40	6.84	6.84	7.46	3.39	4.55	4.55	0.33	0.63	0.00	0.69	1.36	1.49	1.44	1.44	0.00	0.00	0.00	0.00	0.75	0.00	0.80	0.80
			A_{88}			A_{06}	A_{88}			A_{06}	A_{88}			A_{06}	A_{88}			A_{06}	A_{88}			A_{06}	A_{88}			A_{06}
2000	*RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC	18.75	0.00			0.00	0.00			0.00	0.00			0.00	0.00			0.00	0.00			0.00	0.00			0.00
2001	TTLE COTTONWOOD CREEK @ JORDAN RIVER NR SL	105.48	0.71			0.13	0.00			0.28	5.81			16.83	0.05			0.07	0.47			4.59	0.15			0.15
2002	COM FLW JORDAN RIVER & SURPLUS CANAL @ SLC	8,766.42	652.48			584.16	326.00			631.56	135.87			559.07	27.41			46.09	93.72			247.28	24.48			406.53
				A_{92}	A_{00}	A_{06}		A_{92}	A_{00}	A_{06}		A_{92}	A_{00}	A_{06}		A_{92}	A_{00}	A_{06}		A_{92}	A_{00}	A_{06}		A_{92}	A_{00}	A_{06}
2100	*WHITEROCKS RIVER NEAR WHITEROCKS	283.35		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.02	0.02		0.00	0.00	0.00		3.54	4.00	3.97
2101	ROCK CREEK NEAR MOUNTAIN HOME	378.04		0.19	0.00	0.00		0.00	0.19	0.00		0.00	0.00	0.00		1.35	0.04	0.62		0.00	0.00	0.00		4.91	7.14	7.44
2102	YELLOWSTONE RIVER NEAR ALTONAH	335.18		0.49	0.53	1.40		0.00	0.15	0.02		0.09	0.09	0.06		2.30	0.05	2.01		0.10	0.10	0.08		3.09	4.23	4.51
2103	AKE FORK RIVER BL MOON LAKE NR MOUNTAIN HOM	295.95		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.06	0.06		0.00	0.00	0.00		5.23	6.74	6.74
2104	DUCHESNE RIVER NEAR TABIONA	922.99		24.32	23.70	26.87		2.28	4.51	4.18		1.47	0.99	3.04		5.98	0.11	4.60		0.25	0.20	0.42		2.17	3.25	3.06
2105	UCHESNE RIV ABV KNIGHT DIVERSION, NR DUCHESN	1,612.22		29.25	29.60	32.28		2.44	5.12	5.61		1.78	1.24	3.47		13.87	0.21	10.68		0.32	0.21	0.45		7.11	11.83	12.46
			A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}	A_{86}	A_{95}	A_{04}	A_{06}
2200	SEVIER RIVER NEAR KINGSTON	2,926.81	92.27	97.86	101.09	101.10	0.99	7.40	59.77	59.77	12.13	12.03	25.10	25.10	5.55	1.75	0.45	0.45	0.15	1.78	4.36	4.36	7.50	7.78	9.17	9.17
2201	*SEVIER RIVER AT HATCH	868.19	8.09	11.23	10.65	10.66	0.96	0.14	7.49	7.49	5.15	6.14	16.30	16.30	2.00	0.70	0.26	0.26	0.01	0.23	1.50	1.50	2.41	2.64	3.71	3.71
2202	IAMMOTH CREEK ABV WEST HATCH DITCH, NR HATC	272.96	0.00	1.63	1.63	1.63	0.00	0.02	0.18	0.18	1.40	0.95	1.98	1.98	0.00	0.35	0.01	0.01	0.00	0.00	0.00	0.00	0.17	0.04	0.08	0.08

* HCDN station

All areas are in km^2

IR: Irrigated Agricultural Lands

NI: Non - Irrigated Agricultural Lands

RES: Residential Urban Areas

RIP: Non - Agricultural Wetalnds or Other Riparian Type.

URB: All Other Urban Types (i.e. commerical, industrial, etc.)

WATER: Areas of Open Water.

Table 5. *Land covers relative potential evapotranspiration coefficients.*

Land Cover Type	r_{lc}
Coniferous	0.9
Deciduous	0.8
Range/Shrub/Other	0.6
Barren	0.5
Agriculture	1

Table 6. *Study area water balance estimates.*

Watershed ID	Station Name	Q/A (m)				Precipitation (m)				Evaporation (m)	
		min	mean	median	max	min	mean	median	max	actual	potential
1100	BEAR RIVER NEAR UTAH-WYOMING STATE LINE	0.16	0.38	0.37	0.67	0.50	0.98	0.99	1.47	0.60	0.75
1101	BEAR RIVER NEAR RANDOLPH	0.00	0.04	0.04	0.13	0.25	0.49	0.47	0.75	0.44	1.07
1102	BIG CREEK NEAR RANDOLPH	0.02	0.09	0.08	0.22	0.25	0.48	0.46	0.86	0.39	0.65
1200	WEBER RIVER AT GATEWAY	0.03	0.12	0.11	0.30	0.35	0.65	0.65	1.02	0.54	0.94
1201	WEBER RIVER NEAR PLAIN CITY	0.01	0.09	0.08	0.25	0.35	0.66	0.66	1.04	0.57	1.12
1202	SOUTH FORK OGDEN RIVER NEAR HUNTSVILLE	0.09	0.29	0.27	0.65	0.37	0.76	0.74	1.27	0.48	0.61
1203	CENTERVILLE CREEK ABV DIV NR CENTERVILLE	0.12	0.32	0.34	0.55	0.67	1.17	1.14	2.07	0.85	1.24
1204	OGDEN RIVER BL PINEVIEW RES NR HUNTSVILLE	0.03	0.11	0.07	0.25	0.41	0.81	0.78	1.35	0.70	1.41
1300	SALT CREEK AT NEPHI	0.02	0.09	0.08	0.24	0.26	0.51	0.49	0.78	0.42	0.73
1301	CURRANT CREEK NEAR MONA	0.01	0.04	0.03	0.15	0.23	0.45	0.43	0.69	0.40	0.93
1302	WEST CANYON CREEK NEAR CEDAR FORT	0.01	0.05	0.04	0.11	0.54	0.83	0.82	1.23	0.78	2.38
1400	*FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD	0.06	0.27	0.25	0.64	0.33	0.68	0.67	1.00	0.40	0.50
1401	PRICE RIVER AT WOODSIDE	0.01	0.02	0.02	0.09	0.18	0.35	0.34	0.51	0.32	0.90
1402	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT	0.01	0.12	0.13	0.28	0.18	0.41	0.40	0.61	0.29	0.40
1403	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD	0.07	0.21	0.19	0.39	0.34	0.67	0.66	1.03	0.46	0.63
1500	FREMONT RIVER NEAR BICKNELL	0.03	0.04	0.04	0.06	0.27	0.43	0.44	0.56	0.39	0.94
1501	FREMONT RIVER NEAR CAINEVILLE	0.02	0.02	0.02	0.04	0.23	0.37	0.38	0.49	0.35	1.06
1600	EAST FORK SEVIER RIVER NEAR KINGSTON	0.01	0.02	0.02	0.06	0.25	0.40	0.41	0.55	0.38	1.17
1700	COAL CREEK NEAR CEDAR CITY	0.04	0.14	0.13	0.37	0.49	0.75	0.72	1.23	0.61	1.03
1800	VIRGIN RIVER AT VIRGIN	0.03	0.07	0.06	0.17	0.26	0.47	0.47	0.72	0.40	0.77
1801	SANTA CLARA RIVER AT GUNLOCK	0.01	0.03	0.02	0.11	0.15	0.43	0.41	0.73	0.40	1.11
1802	EAST FORK VIRGIN RIVER NEAR GLENDALE	0.04	0.08	0.07	0.21	0.23	0.41	0.40	0.64	0.33	0.55
1803	NORTH FORK VIRGIN RIVER NEAR SPRINGDALE	0.04	0.10	0.08	0.25	0.33	0.56	0.55	0.85	0.46	0.80
1804	SANTA CLARA RIVER ABV BAKER RES, NR CENTRAL	0.00	0.02	0.01	0.08	0.19	0.56	0.54	0.96	0.54	1.96
1900	*BLACKSMITH FORK AB UP and L CO.'S DAM NR HYRUM	0.07	0.17	0.16	0.39	0.36	0.66	0.66	1.12	0.49	0.74
1901	COM F LOGAN R AB ST D AND LO HP AND SM C N LO	0.19	0.39	0.38	0.74	0.59	0.98	0.99	1.53	0.59	0.73
1902	LITTLE BEAR RIVER AT PARADISE	0.07	0.18	0.17	0.34	0.46	0.83	0.82	1.35	0.65	1.05
2000	*RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC	0.05	0.20	0.17	0.60	0.45	0.88	0.87	1.37	0.68	1.06
2001	LITTLE COTTONWOOD CREEK @ JORDAN RIVER NR SLC	0.16	0.41	0.32	0.99	0.69	1.24	1.24	1.93	0.83	1.12
2002	COM FLW JORDAN RIVER & SURPLUS CANAL @ SLC	0.02	0.05	0.04	0.22	0.29	0.53	0.52	0.83	0.47	1.06
2100	*WHITEROCKS RIVER NEAR WHITEROCKS	0.13	0.35	0.34	0.66	0.43	0.71	0.71	1.03	0.36	0.42
2101	ROCK CREEK NEAR MOUNTAIN HOME	0.09	0.36	0.38	0.63	0.43	0.78	0.78	1.22	0.42	0.50
2102	YELLOWSTONE RIVER NEAR ALTONAH	0.17	0.37	0.36	0.63	0.31	0.63	0.62	0.95	0.27	0.29
2103	LAKE FORK RIVER BL MOON LAKE NR MOUNTAIN HOME	0.17	0.38	0.38	0.64	0.34	0.67	0.66	0.99	0.28	0.31
2104	DUCHESNE RIVER NEAR TABIONA	0.07	0.18	0.19	0.34	0.37	0.65	0.65	1.04	0.47	0.68
2105	DUCHESNE RIV ABV KNIGHT DIVERSION, NR DUCHESNE	0.06	0.17	0.17	0.32	0.33	0.59	0.59	0.93	0.43	0.61
2200	SEVIER RIVER NEAR KINGSTON	0.02	0.04	0.03	0.11	0.33	0.47	0.45	0.66	0.43	1.09
2201	*SEVIER RIVER AT HATCH	0.04	0.12	0.11	0.32	0.42	0.63	0.61	1.01	0.51	0.87
2202	MAMMOTH CREEK ABV WEST HATCH DITCH, NEAR HATCH	0.03	0.15	0.14	0.37	0.50	0.80	0.76	1.43	0.65	1.09

* HCDN station

Table 7. *Runoff sensitivity to change in Coniferous land cover percentage (acre-ft/mi^2/yr).*

Watershed ID	Station Name	Coniferous to All except Agriculture			Coniferous to All except Agriculture		
		$Coeff [C:0.9,D:0.8,R:0.6,B:0.5,A:1.0]			$Coeff [C:0.8,D:0.9,R:0.6,B:0.5,A:1.0]		
		curve parameter			curve parameter		
		v=1.5	**v=2	v=10	v=1.5	**v=2	v=10
1100	Bear River near Utah-Wyoming State Line	-244.738	-293.576	-466.978	-140.623	-168.651	-267.415
1101	Bear River near Randolph	-39.802	-49.862	-120.274	-26.878	-34.188	-99.181
1102	Big Creek near Randolph	-75.349	-93.042	-222.485	-51.419	-64.191	-163.279
1200	Weber River at Gateway	-84.892	-105.532	-263.591	-47.321	-59.570	-158.092
1201	Weber River near Plain City	-67.988	-84.881	-213.326	-37.169	-47.155	-135.118
1202	South Fork Ogden River near Huntsville	-136.168	-164.694	-299.743	-49.046	-59.214	-100.269
1203	Centerville Creek ABV DIV nr Centerville	-196.120	-241.910	-534.400	-90.087	-111.535	-236.301
1204	Ogden River BL Pineview Res nr Huntsville	-71.886	-90.090	-234.081	-29.684	-37.880	-112.467
1300	Salt Creek at Nephi	-69.830	-86.201	-202.389	-44.881	-56.207	-146.821
1301	Currant Creek near Mona	-37.520	-46.989	-114.633	-24.896	-31.654	-92.029
1302	West Canyon Creek near Cedar Fort	-39.927	-50.063	-111.840	-24.370	-31.222	-94.245
1400	*Fish Creek above Reservoir, near Scofield	-106.901	-128.448	-217.948	-19.776	-23.658	-37.162
1401	Price River at Woodside	-20.794	-25.706	-47.773	-14.501	-18.335	-47.440
1402	White R BL Tabbyune CRK nr Soldier Summit	-77.943	-95.657	-199.140	-40.493	-49.790	-99.318
1403	Mud CRK BL Winter Quarters Cyn @ Scofield	-82.539	-101.279	-195.100	1.674	2.054	3.818
1500	Fremont River near Bicknell	-35.922	-44.842	-103.474	-24.239	-30.768	-87.421
1501	Fremont River near Caineville	-21.249	-26.454	-53.341	-15.219	-19.311	-51.390
1600	East Fork Sevier River near Kingston	-21.506	-27.386	-76.179	-13.903	-17.930	-58.727
1700	Coal Creek near Cedar City	-99.213	-124.555	-322.637	-42.602	-53.842	-139.276
1800	Virgin River at Virgin	-60.273	-74.072	-157.116	-43.376	-54.192	-138.561
1801	Santa Clara River at Gunlock	-27.797	-34.452	-67.026	-20.334	-25.686	-65.899
1802	East Fork Virgin River near Glendale	-72.187	-89.623	-222.154	-52.657	-65.826	-167.299
1803	North Fork Virgin River near Springdale	-78.695	-97.337	-233.709	-49.760	-62.366	-162.966
1804	Santa Clara River ABV Baker Res, nr Central	-21.966	-28.126	-81.613	-14.657	-18.981	-64.293
1900	*Blacksmith Fork AB UP And L CO.'S Dam nr Hyrum	-108.046	-133.728	-306.481	-52.563	-65.354	-145.020
1901	Com F Logan R AB ST D and LO HP and SM C N LO	-197.031	-236.364	-386.443	-84.913	-101.663	-161.071
1902	Little Bear River at Paradise	-109.810	-136.472	-335.095	-44.050	-55.260	-134.288
2000	*Red Butte Creek at Fort Douglas, near SLC	-132.832	-164.048	-392.299	-69.233	-86.357	-206.518
2001	Little Cottonwood Creek @ Jordan River nr SLC	-327.424	-399.230	-792.015	-227.445	-277.549	-532.207
2002	Com FLW Jordan River & Surplus Canal @ SLC	-45.860	-57.461	-142.868	-28.883	-36.755	-108.171
2100	*Whiterocks River near Whiterocks	-240.754	-278.545	-364.979	-178.677	-206.961	-272.773
2101	Rock Creek near Mountain Home	-244.339	-284.775	-382.730	-169.954	-198.490	-270.047
2102	Yellowstone River near Altonah	-199.356	-225.181	-271.715	-145.155	-164.028	-198.194
2103	Lake Fork River BL Moon Lake nr Mountain Home	-215.267	-242.298	-288.834	-161.274	-181.846	-218.007
2104	Duchesne River near Tabiona	-123.348	-152.172	-326.877	-66.163	-81.793	-170.212
2105	Duchesne River ABV Knight Diversion, nr Duchesne	-121.398	-149.832	-317.066	-70.952	-87.689	-181.085
2200	Sevier River near Kingston	-38.246	-48.522	-134.916	-26.718	-34.237	-106.575
2201	*Sevier River at Hatch	-114.806	-145.315	-372.913	-75.123	-95.164	-243.673
2202	Mammoth Creek ABV West Hatch Ditch, near Hatch	-140.114	-177.564	-451.703	-82.086	-104.059	-264.494

* HCDN station

**v=2 i.e. Budyko relation

$C=Coniferous, D=deciduous, R=Range/Shrub/Others, B=Barren, and A=Agriculuture

Table 8. *Runoff sensitivity to changes in Range/Shrub/Other land cover percentage (acre-ft/mi²/yr).*

Watershed ID	Station Name	Range/Shrub/Others to All			Range/Shrub/Others to All			Range/Shrub/Others to forest only			Range/Shrub/Others to forest only		
		$Coeff [C:0.9,D:0.8,R:0.6,B:0.5,A:1.0]			$Coeff [C:0.8,D:0.9,R:0.6,B:0.5,A:1.0]			$Coeff [C:0.9,D:0.8,R:0.6,B:0.5,A:1.0]			$Coeff [C:0.8,D:0.9,R:0.6,B:0.5,A:1.0]		
		curve parameter			curve parameter			curve parameter			curve parameter		
		v=1.5	**v=2	v=10	v=1.5	**v=2	v=10	v=1.5	**v=2	v=10	v=1.5	**v=2	v=10
1100	Bear River near Utah-Wyoming State Line	179.884	214.732	322.151	147.743	176.513	267.137	256.444	306.316	462.582	216.647	258.941	393.647
1101	Bear River near Randolph	39.252	49.744	138.506	38.325	48.608	136.571	37.199	46.833	120.494	35.696	45.021	118.380
1102	Big Creek near Randolph	68.510	84.719	204.844	66.333	82.122	200.212	68.811	85.070	205.319	66.620	82.460	200.715
1200	Weber River at Gateway	86.476	108.915	289.209	96.441	121.284	320.871	84.524	106.255	280.883	96.561	121.112	317.724
1201	Weber River near Plain City	72.202	91.714	264.463	80.884	102.553	292.581	68.816	87.199	247.946	79.530	100.479	280.181
1202	South Fork Ogden River near Huntsville	151.384	182.622	303.913	183.583	221.509	370.251	154.225	186.065	310.215	186.902	225.538	377.828
1203	Centerville Creek ABV DIV nr Centerville	216.858	268.563	565.892	233.278	288.855	610.207	218.263	270.295	569.874	234.731	290.642	614.363
1204	Ogden River BL Pineview Res nr Huntsville	88.110	112.962	341.413	104.880	134.325	404.435	81.813	104.671	314.054	101.332	129.401	385.093
1300	Salt Creek at Nephi	54.899	68.837	180.749	61.878	77.384	200.651	64.013	79.830	203.687	71.760	89.168	221.782
1301	Currant Creek near Mona	42.662	54.103	153.081	43.395	55.004	154.759	33.776	42.612	113.818	35.581	44.797	116.753
1302	West Canyon Creek near Cedar Fort	38.178	48.683	138.120	40.026	50.948	141.123	39.964	50.823	139.043	41.825	53.089	141.509
1400	*Fish Creek above Reservoir, near Scofield	136.925	163.412	249.402	172.918	206.302	313.825	137.012	163.515	249.567	173.016	206.420	314.016
1401	Price River at Woodside	14.455	18.447	53.901	15.210	19.378	55.435	18.919	23.716	54.353	19.884	24.849	54.430
1402	White R BL Tabbyune CRK nr Soldier Summit	76.931	94.615	187.040	78.445	96.475	190.863	82.915	101.954	203.062	84.481	103.878	207.074
1403	Mud CRK BL Winter Quarters Cyn @ Scofield	138.611	169.788	290.153	149.440	183.007	310.800	138.141	169.221	289.565	149.066	182.559	310.451
1500	Fremont River near Bicknell	31.327	39.654	109.191	30.509	38.655	107.550	33.832	42.502	106.686	32.839	41.311	105.506
1501	Fremont River near Caineville	11.154	14.478	51.190	10.151	13.192	47.253	20.290	25.666	65.437	18.886	23.967	63.932
1600	East Fork Sevier River near Kingston	20.402	26.224	82.439	18.358	23.657	76.754	21.351	27.294	79.974	19.069	24.461	74.970
1700	Coal Creek near Cedar City	94.425	120.262	300.941	98.367	125.301	313.247	120.664	153.509	386.849	125.149	159.229	401.039
1800	Virgin River at Virgin	32.250	40.754	113.458	33.167	41.890	116.265	53.096	65.798	154.733	54.364	67.286	155.993
1801	Santa Clara River at Gunlock	24.580	30.379	56.550	21.495	26.836	58.222	25.232	31.071	54.619	21.965	27.354	57.191
1802	East Fork Virgin River near Glendale	60.324	74.928	186.185	47.082	58.805	149.173	67.235	83.012	198.723	51.310	63.873	160.327
1803	North Fork Virgin River near Springdale	59.381	74.679	197.176	65.453	82.193	216.139	74.267	92.823	239.562	81.069	101.099	257.799
1804	Santa Clara River ABV Baker Res, nr Central	21.506	27.468	76.907	18.406	23.639	71.555	21.296	27.164	74.650	18.021	23.129	69.357
1900	*Blacksmith Fork AB UP And L CO.'S Dam nr Hyrum	115.280	143.398	316.441	121.033	150.533	332.702	118.684	147.601	326.502	124.510	154.822	343.034
1901	Com F Logan R AB ST D and LO HP and SM C N LO	209.372	250.061	384.175	206.921	247.135	379.717	227.844	272.232	420.240	225.275	269.163	415.519
1902	Little Bear River at Paradise	128.371	161.371	387.890	150.251	188.795	454.850	126.253	158.619	382.529	149.724	187.994	454.699
2000	*Red Butte Creek at Fort Douglas, near SLC	132.226	164.824	394.846	156.908	195.223	469.517	134.362	167.445	401.400	159.172	197.980	476.349
2001	Little Cottonwood Creek @ Jordan River nr SLC	116.846	142.501	251.123	90.800	110.741	195.466	312.046	380.836	703.759	268.286	327.418	601.595
2002	Com FLW Jordan River & Surplus Canal @ SLC	49.840	63.455	187.525	51.579	65.617	192.484	43.125	54.600	152.889	46.217	58.385	159.664
2100	*Whiterocks River near Whiterocks	105.838	121.852	155.859	69.558	80.344	104.371	208.100	239.432	305.354	153.345	176.906	228.455
2101	Rock Creek near Mountain Home	138.932	161.349	212.537	98.512	114.758	153.748	221.813	257.491	338.416	167.626	195.113	260.219
2102	Yellowstone River near Altonah	77.106	86.385	101.544	51.422	57.798	68.622	172.399	192.885	225.834	130.811	146.751	173.208
2103	Lake Fork River BL Moon Lake nr Mountain Home	92.813	103.998	122.236	61.173	68.816	81.877	181.772	203.372	237.974	134.123	150.579	178.034
2104	Duchesne River near Tabiona	113.607	140.625	282.633	110.462	136.733	274.776	131.949	163.227	334.394	128.216	158.613	324.728
2105	Duchesne River ABV Knight Diversion, nr Duchesne	100.035	123.785	245.969	89.916	111.264	221.147	126.371	156.278	317.479	114.162	141.189	286.291
2200	Sevier River near Kingston	31.536	40.430	126.476	26.246	33.765	109.364	36.484	46.273	128.251	29.997	38.280	113.946
2201	*Sevier River at Hatch	90.222	114.681	289.039	69.913	88.830	224.448	113.890	144.421	368.245	90.044	114.193	291.123
2202	Mammoth Creek ABV West Hatch Ditch, near Hatch	103.681	132.375	320.362	84.000	107.133	261.908	149.936	191.281	466.321	125.095	159.456	391.647

* HCDN station

**v=2 i.e. Budyko relation

$C=Coniferous, D=deciduous, R=Range/Shrub/Others, B=Barren, and A=Agriculuture

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