Development of a in Integrated Land and Water Use Planning Tool for the Carson River Watershed: Phase I Development of a Planning Platform and Water Resources Assessment

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1. Background and Introduction

1.1 Geography

The Carson River's headwaters form in the mountains south of the Lake Tahoe Basin, just north of Sonora Pass (see Figure 1). In its beginning stages, largely in Alpine County, California, the river is actually two distinct rivers: the East and West Fork. The two forks remain distinct entities as they cross the state line into Nevada, where they begin to feed a number of smaller ditches used for irrigation. As the forks make their way into the Carson Valley in Douglas County, Nevada, the size and number of ditch diversions increase to the extent that much of the valley is flooded, and groundwater flow becomes a significant mode of flow transport in the valley. After the two forks merge, the river exits Eagle Valley and continues on to Lahontan Reservoir, where its water is stored for eventual transport to the Newlands Irrigation Project near Fallon, Nevada. The Carson River Basin is located in both California and Nevada, encompassing an area of approximately 3,966 square miles of which approximately 15%, or 606 square miles, lie in California with the remaining 85%, or approximately 3360 square miles, lying in Nevada (Horton, 1997b). The Carson River Watershed is hydrologically connected to both the Truckee River Watershed and the Humboldt River Watershed. The connection to the Truckee River is via a constructed canal (the Truckee-Carson Canal) that transports water from the Truckee River to Lahontan Reservoir. The connection of the Humboldt River Watershed to the Carson River Watershed occurs when the terminus of the Carson River (the Carson Sink) and the terminus of the Humboldt River (the Humboldt Sink) merge during years of high water flow (see Figure 2). Neither of these connections affect flow conditions or water management upstream of Lahontan Reservoir in the Carson River, which is the geographical area of focus for this project.

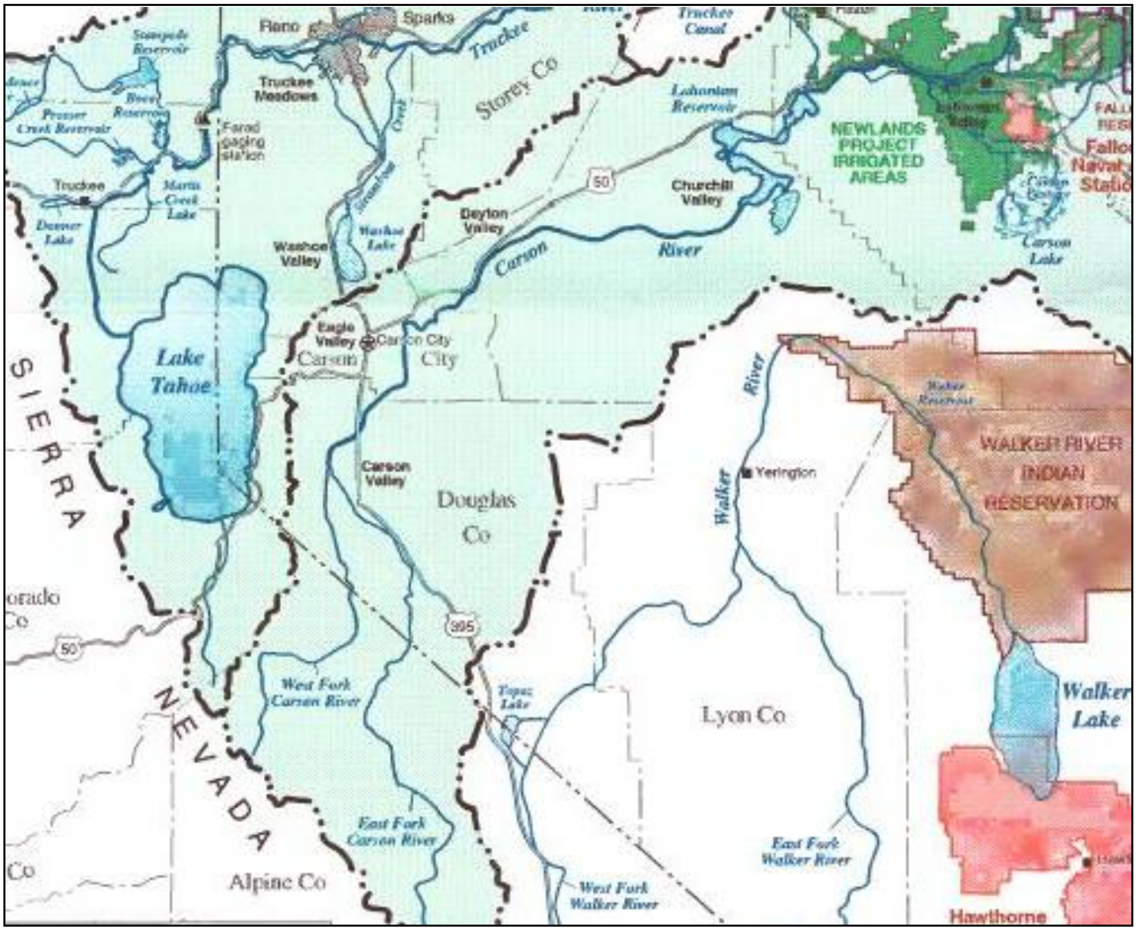
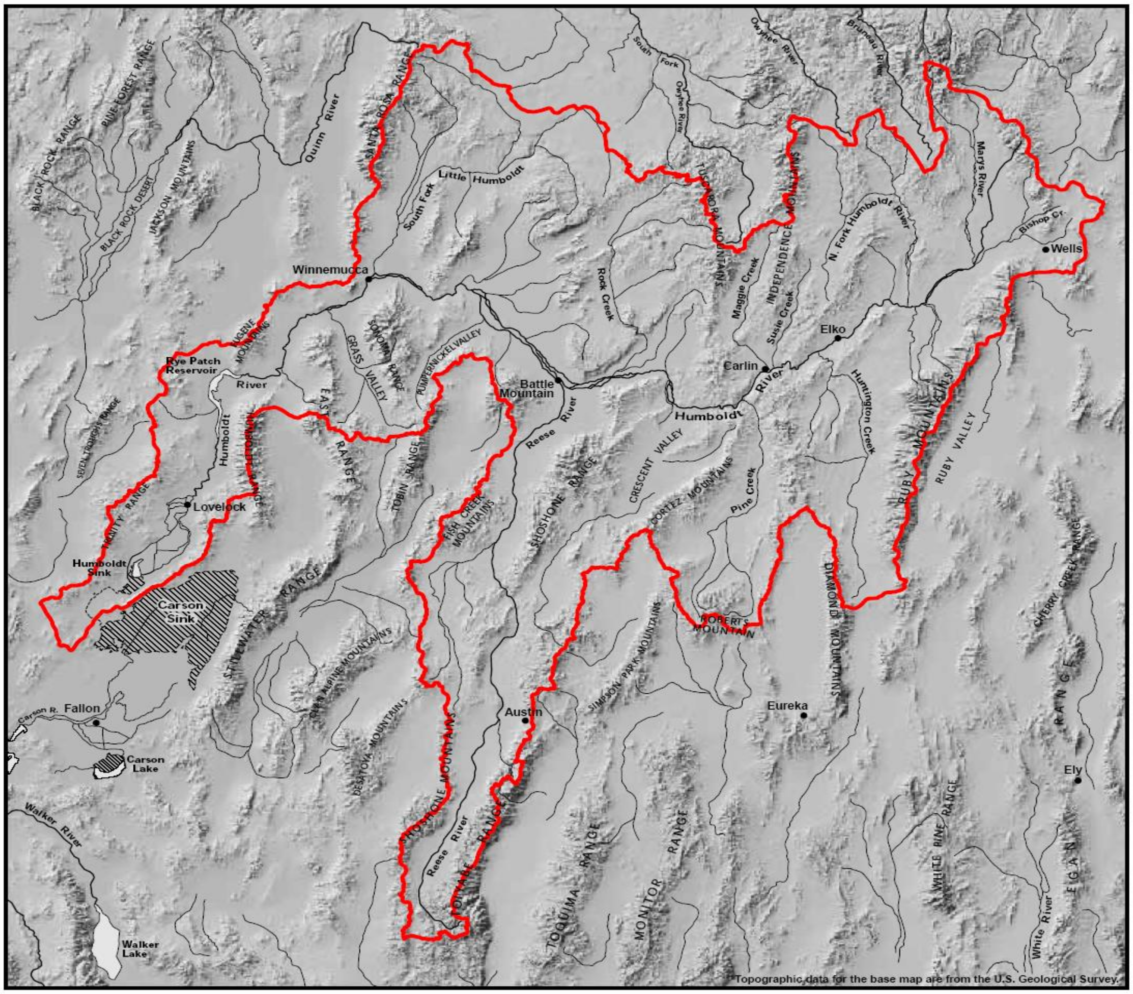


Figure 1. Map of Carson River Basin.

The Carson River Basin is connected to the Truckee River via the Truckee Canal. That connection is outside the realm of the report and model, however. Thus the Truckee River receives little attention here. The same can also be said of the Humboldt River Basin, pictured in Figure 2. However unlike the Truckee-Carson Basin surface water connection that exists every year, surface water only flows from the Humboldt Sink to the Carson Sink in very wet years (Figure 2).



Topographic data for the base map are from the U.S. Geological Survey.

Figure 2. Map of the Humboldt River Basin, Nevada (Nevada Bureau of Mines and Geology, 2005).

1.2 Geology

The area of study within the Upper Carson River Basin consists of three hydrographic areas: Carson Valley, Eagle Valley, and Dayton Valley (see Figure 3). These valleys were formed by structural depressions and were then filled by alluvial and lacustrine deposits (Maurer, 1986). Lacustrine, or lake, deposits originated from Lake Lahontan which long ago covered a peak surface area of approximately 8,655 square miles of Northern Nevada and enveloped the Lahontan Valley wetlands where Stillwater National Wildlife Refuge now exists up to a depth of approximately 700 feet. Over thousands of years, the lake receded and grew in various cycles, resulting in an estimated average sediment thickness of 3,000 feet underlying the basin (US Bureau of Reclamation, 1990). The area of study is “basin and range” meaning it is characterized by isolated long, narrow mountain ranges and intervening broad, flat valleys (Maurer, 1986). The Upper Carson River borders the Carson mountain range (part of the Sierra Nevada Range) to the west, the Pine Nut mountain range to the east, and the Sierra Nevada range, the dominant geologic feature in the area, to the southwest. Elevation ranges from approximately 4,600 feet in the Pine Nut mountain range to approximately 10,000 feet in the Carson mountain range to approximately 11,000 feet in the Sierras (ACRC and CVCD, 1996).

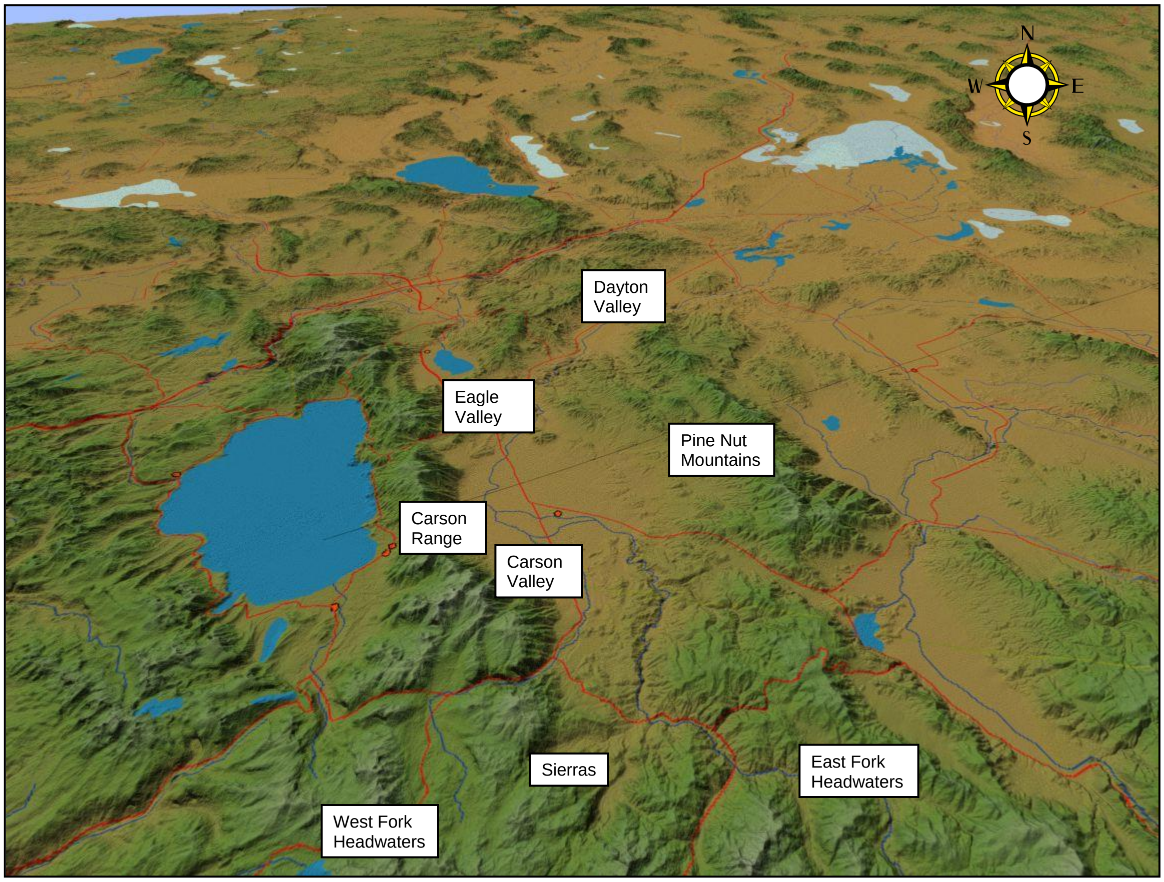


Figure 3. Map of Carson River Basin Mountain Ranges and Valleys (Google Images, 2005).

1.3 Soils

Soil types vary in the Upper Carson River Basin and are largely dependant upon elevation. For this report, detailing the specific classifications of soil in the valleys is not as important as understanding how the soil is able to sustain significant acres of agriculture in the desert. In general, the valleys the Carson River traverses through contain basin-fill soils that provide fertile ground for the approximately 38,000 acres of agriculture currently in production (ACRC and CVCD, 1996). The soils are such that they are able to absorb large quantities of groundwater from flood irrigation and percolation from mountain streams. Further, they can release large quantities of groundwater to ditches that partially or entirely rely on return flows from flood irrigation. While traditional specific soil classifications are not relevant to the present work, the terms “bench land” and “bottom land” are helpful in understanding the implications of the governing law of the Carson River, the 1980 Alpine Decree. Horton (1997b) best describes the bench land and bottom land distinction:

> The term "bench land" is a general term describing porous and coarse-textured (sandy-gravelly) well-drained soils, overlying a deep water table (if occurring), that exhibits relatively low water holding capacity and rapid infiltration of irrigation water. The term "bottomland," or "bottom land," represents a general term describing generally rich, loamy or fine-textured and poorly drained soils, overlying a shallow water table or possibly adjacent to a stream, lake or other body of water, that exhibits relatively good water holding capacity and slow to moderate infiltration of irrigation water. Bottom lands are often associated with a river's flood plain. The U.S. Department of the Interior, Bureau of Reclamation (USBR) criteria (revised 1992) has defined bottom land for Nevada's Newlands Irrigation Project as "those lands with a five-foot soil profile having a holding capacity equal to or exceeding 8 inches and/or a water table within 6 feet of the surface for a period equal to or exceeding 150 days. If neither of these factors applies, the land is designated as bench land." Lands classified as bench (or bottom) according to USBR criteria, above, will be limited to maximum water deliveries (duty) in accordance to the provision of the 1944 Orr Ditch Decree and the 1980 Alpine Decree, which are identical in establishing water duties and establish the following limits.

In the Carson River Basin specific water duties are allocated based on the above distinction in conjunction with location (above or below Lahontan Reservoir). These water duties will be detailed later in the report in Section 3.3.

1.4 Climate

The Upper Carson River Basin is characterized by short, hot summers and long, moderately cold winters. The climate is dry, thus evaporation rates are high, typically on the order of 30 to 36 inches (net evaporation) per year (CDWR, 1991). Temperature is largely a function of elevation. The average annual temperature ranges from 52˚F in the valleys to 33˚F in the mountain ranges. The average winter temperature is 33˚F with an average minimum of 19˚F. In the summer, the average temperature is 66˚F with an average maximum temperature of 87˚F (ACRC and CVCD, 1996). During daylight hours, the sun shines 78% of the time: 90% during the summer and 66% during the winter on average (Douglas County Master Plan, 2005).

While most of the Carson River's surface area and demand for use lie within the State of Nevada, most of the basin's precipitation falls in the State of California (Horton, 1997a). The Sierra Nevada mountain range acts as a barrier to eastern air flow so precipitation, like temperature, is largely a function of elevation. Table 1 (National Weather Service, 2005) and Table 2 (CDWR, 1991) illustrate this point.

Table 1. Elevations and Precipitation Data for Selected Locations

Station	State	Elevation	Water Year Avg. (Oct-Sep)
Ebbetts Pass SNOTEL	CA	8700'	55.98
Blue Lakes SNOTEL	CA	8000'	47.37
Caples Lake	CA	8000'	46.45
Poison Flat SNOTEL	CA	7900'	34.2
Spratt Creek SNOTEL	CA	6150'	31.11
Grover Hot Springs	CA	5900'	28.23
Markleeville	CA	5500'	18.7
Carson City	NV	4700'	10.36
Minden	NV	4700'	8.38
Lahontan Dam	NV	4100'	5.3
Fallon	NV	3900'	5.3

Table 2. Elevation and Frost Data for Selected Locations

Location	Elevation (feet)	Frost-Free Season (days)
Tahoe City, CA	6630	77
Minden, NV	4700	104
Carson City, NV	4675	123
Reno, NV	4400	129
Fallen, NV	3950	150

Precipitation is not solely a function of elevation, however. This is evidenced by the non-uniform average precipitation of Carson River Basin's different valleys. For example, Dayton Valley is drier than the rest of the basin, receiving an estimated 5-6 inches of rain per year on the valley floor compared to an average of 8-9 inches at Minden in Carson Valley and an average of 10-11 inches in Carson City at the Eagle Valley station (National Weather Service, 2005).

Despite the rain barrier, the Pine Nut Mountains to the east of the valley still receive significant amounts of precipitation: up to 26 inches per year. However, when compared to the Carson Range (up to 45 inches) and the Sierras (up to 60 inches), this seems less significant, though it is more than two and one half times the 10 inches the valley below typically receives. Approximately 92% of all precipitation is associated with winter storms from October to May, with the remainder falling as rain during the summer (Kennedy/Jenks/Chilton, 1988).

Annual precipitation can and does vary widely from year to year, so the idea of an average water year is more of a theoretical concept used for long term forecasting as opposed to an actual amount of precipitation that can be expected on an individual year to year basis. Further, wet years and dry years sometimes run in cycles. For example, three to five wet years are often be followed by three to five drought years and so on. Figure 4 (data courtesy Horton, 1997b) illustrates this point nicely.

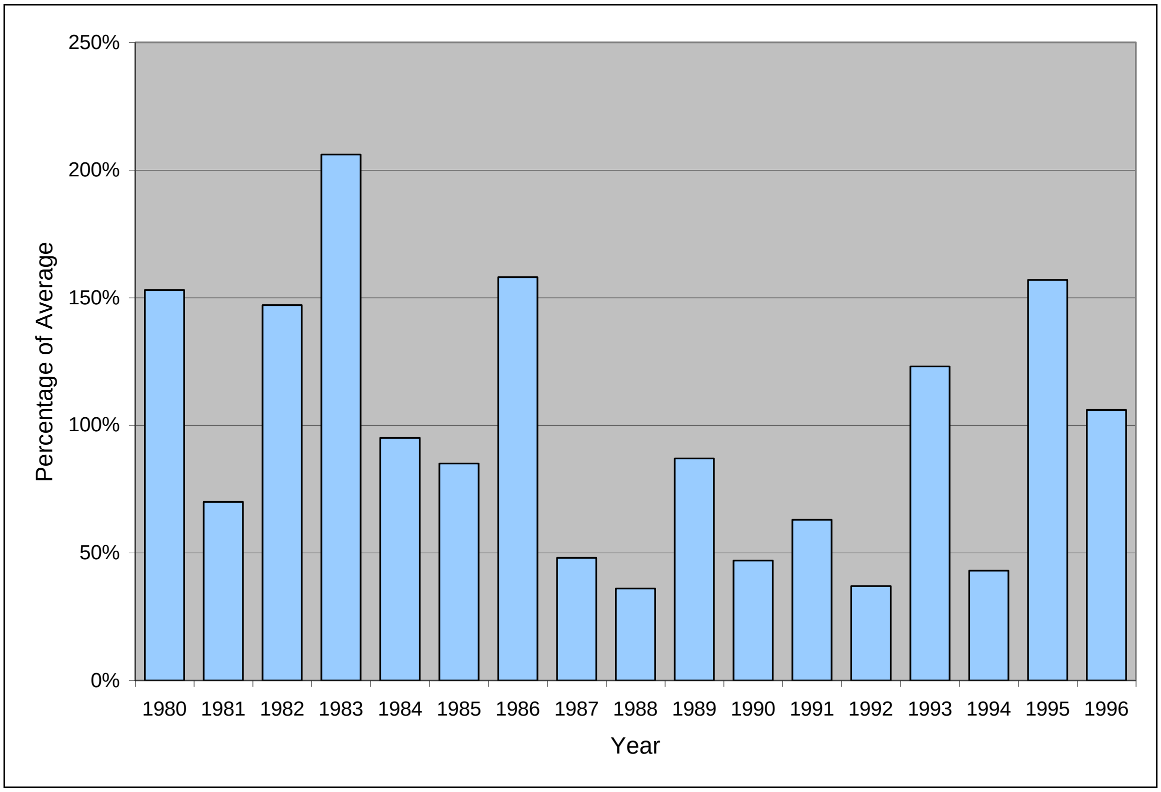


Figure 4. Carson River Basin Snow Water Content as a Percentage of Average.

As can be seen by looking at the years 1980 through 1996, the years 1982-1986 tended to be heavy precipitation years, averaging 138% of normal. These wet years were followed by a series of dry years, 1987-1992, which averaged 53% of normal. This drought was then followed by more wet years. Overall, the average for the seventeen year period is 98% of normal. However, only the years 1984 and 1996 individually experienced near-average precipitation conditions of 95% and 106% respectively (Horton, 1997b).

1.5 Hydrology of the Carson River

1.5.1 Previous Studies of Carson River Hydrology

The Carson River's flow has been monitored for decades, and in some reaches, for over one hundred years. There have been numerous studies of the hydrology of the Carson

River, each with their own foci including, but not limited to water quality, water quantity, river history, river operations, and the influence that ungaged tributaries have on the Carson River.

Many of the reports have focused on water quality, as due to significant mining in the area in the past, mercury is prevalent in and along many of the lower reaches of the Carson River. Authors of *Total Mercury in Sediment, Water and Fishes in the Carson River Drainage, West-Central Nevada* (NDEP, 1985) concluded that mercury concentrations of soils below the old mill sites are 200 times greater than those above. Subsequent US Environmental Protection Agency (EPA) investigations resulted in a Superfund designation of several reaches of the Carson River near Dayton as well as Lahontan Reservoir, Stillwater National Wildlife Refuge (NWR), Indian Lakes in Lahontan Valley, and several tributaries to the Carson River (EPA, 1990). Some remediation has occurred, along with continued investigation as to what the best solution is to the mercury problem.

Others reports have focused on estimating water resources and determining the feasibility of various projects that could lead to optimization of water resource availability. Authors of *The Carson River Management Pro*gram (Kennedy/Jenks/Chilton, 1988) did extensive research on water rights to identify opportunities for resource development within existing water rights, as the both the ground and surface waters of the Upper Carson River Basin are fully appropriated. A notable conclusion of the report was that approximately 35,000 acre-feet of groundwater permits and certificates issued in Carson Valley for municipal purposes had not yet been fully developed (1988).

Ten years later, Kennedy/Jenks/Chilton followed up with another study, *Water Resource Analysis of the Upper Carson River Basi*n (Kennedy/Jenks/Chilton, 1998). This study served to provide an update on the water budget analysis for the Carson Water Subconservancy District (CWSD) based in part on a 1991 model of the river and its diversions using MODSIM (Kennedy/Jenks, 1991). Another goal of the study was to provide the United States Fish and Wildlife Service (FWS), co-sponsors of the study, with pertinent information concerning how they could best meet their objectives of providing 125,000 acre-feet of water for 25,000 acres of wetlands at Stillwater NWR. This report concluded that success in bringing more water to Stillwater NWR would be best achieved by purchasing/retiring water rights near Fort Churchill, NV first, and then progressing upstream (Kennedy/Jenks, 1991). This is because as one moves farther upstream, the probability increases that remaining agricultural demands placed on the river would make any water right acquisition moot.

Other reports focused on providing an historical context to the river. By far, the most comprehensive historical documentation of the Carson River is *The Carson River Chronology* (Horton, 1997b). Horton starts in 1900 and methodically describes the many interesting events and circumstances that shaped the river's history. The only downfall to this piece, if there is one, is that it does not receive periodic updates. Its first and only update was in 1997. Another report that provides its reader with a thorough historical understanding of the Carson River is *The Carson River Atlas* (CDWR, 1991). As with Horton's *Chronology*, the *Atlas's* only negative characteristic is that it has not been updated recently.

Carson River operations were explored in the report titled *River-Operations Model for Upper Carson River Basin, California and Nevada* (Hess and Taylor, 1998). The report provides its reader with a cursory overview as to how the river operates and selectively describes some of the daily river operations that are part and parcel to its accompanying model.

Some groundwater studies have been done, notably by Maurer et al. (1986 and 1994). While these studies accomplish their tasks of simulating groundwater pumpage (1986) and gaining insight into the potential for, and the possible effects of, artificial recharge of aquifers in the Carson Valley (1994), they do not directly address the way valley groundwater flow regimes seasonally change in response to flood irrigation for agriculture. The latter would have been useful for this project.

Maurer et al. have also delved into surface water flows in the Carson River Basin in *Updated Computations and Estimates of Streamflows Tributary to Carson Valley, Douglas County, Nevada and Alpine County, California, 1990-2002*. That report studied the influence that gaged, and more notably ungaged, tributaries have on Carson River flow. This study's conclusions nearly doubled some of the previous estimates regarding Carson River tributary flow, and it is these new estimates that are used in the work presented later in this study..

1.5.2 Surface Water Hydrology of the Carson River

In the Upper Carson River watershed, the Carson River begins as two distinct rivers: the West Fork and the East Fork. Both forks originate in the Sierras and at these high elevations both forks share a similarly steep gradient. For administrative purposes via the Alpine Decree (discussed in detail in **Section 3.3**), the river has been broken into eight different segments. The maps that follow, while useful for visualizing the locations of various ditches and sloughs, will also be referred to later in Section 3.3 when detailing the boundaries and regulations governing the eight separate segments of the Carson River.

1.5.3 The West Fork of the Carson River

The West Fork is the smaller of the two forks, historically averaging less than one third the flow of the East Fork at their respective headwater gages (76,600 vs. 259,150 acre-feet; period of record 1961-2003; see Appendix A). The West Fork begins in the vicinity of Lost Lakes at an elevation of approximately 8,600 feet (Horton, 1997b). As the river makes its way towards the valley, numerous creeks and streams merge with it and gradually increase its flow. Soon after encountering the first USGS gage on the West Fork at Woodfords, CA, the West Fork encounters its first series of agricultural diversions (Figure 5).

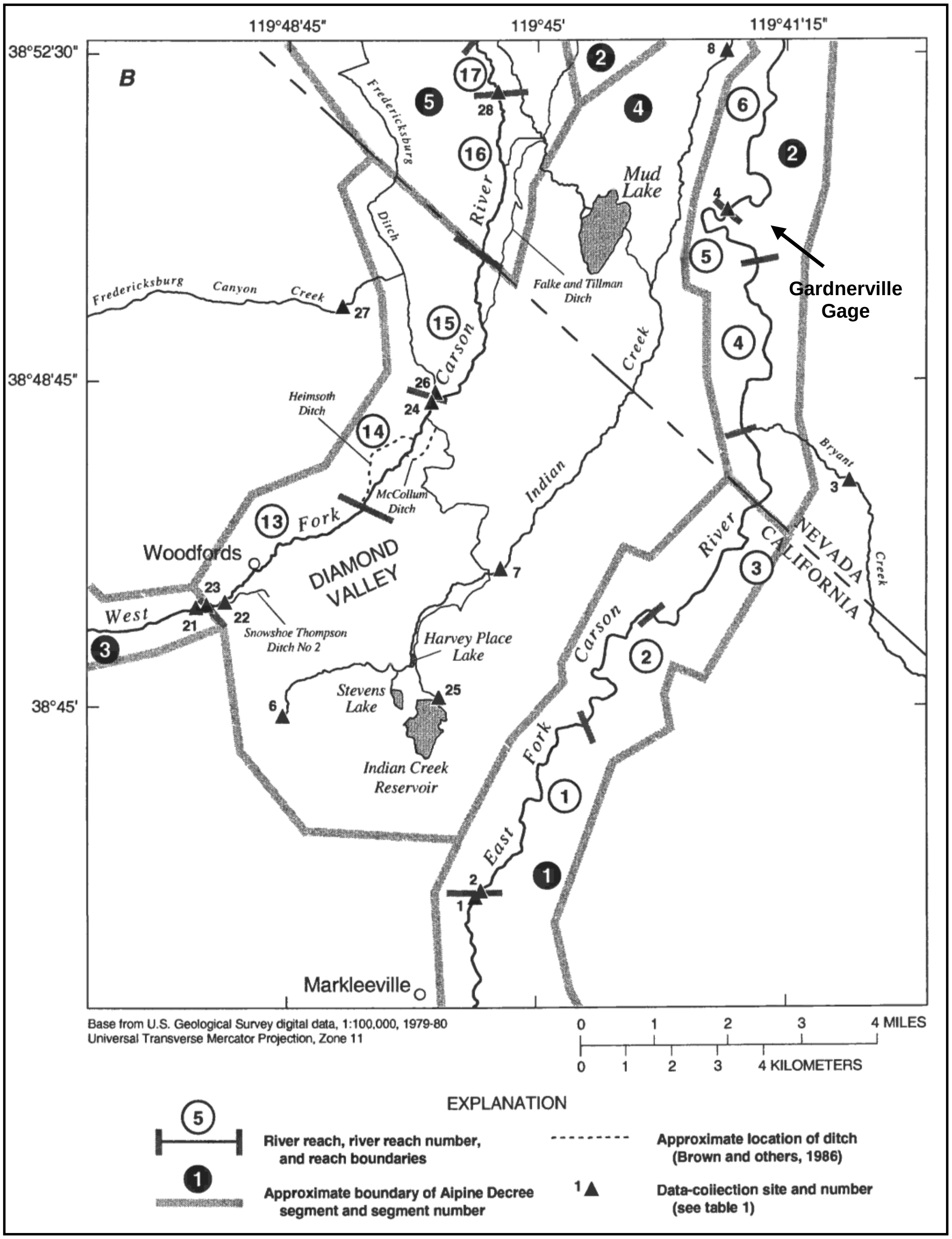


Figure 5. Map of Segments 1, 2 and 3, 4 and 5 (Hess and Taylor, 1999).

These and subsequent ditches divert water during the irrigation season only, typically from mid-March through mid-October, with flow in March and October not as common and dependant on necessity (March) and availability (October). Flow in these and subsequent diversions typically peaks in May and gradually decreases as the summer progresses.

The first ditches (Snowshoe Thompson Ditches No. 1 and 2) irrigate Diamond Valley as well as transport water to Mud Lake via Indian Creek. As the West Fork continues northeast toward Paynesville, CA more water is diverted by ditches such as the Heimsoth Ditch and the McCollum Ditch. After flowing through Paynesville, the West Fork encounters the Fredricksburg Ditch, which runs north essentially parallel to the West Fork, and eventually returns some of its flow, via surface and groundwater return flows from other ditches, to the Brockliss Slough, after supplying irrigation water for thousands of acres of land along the way (Figures 5 and 6).

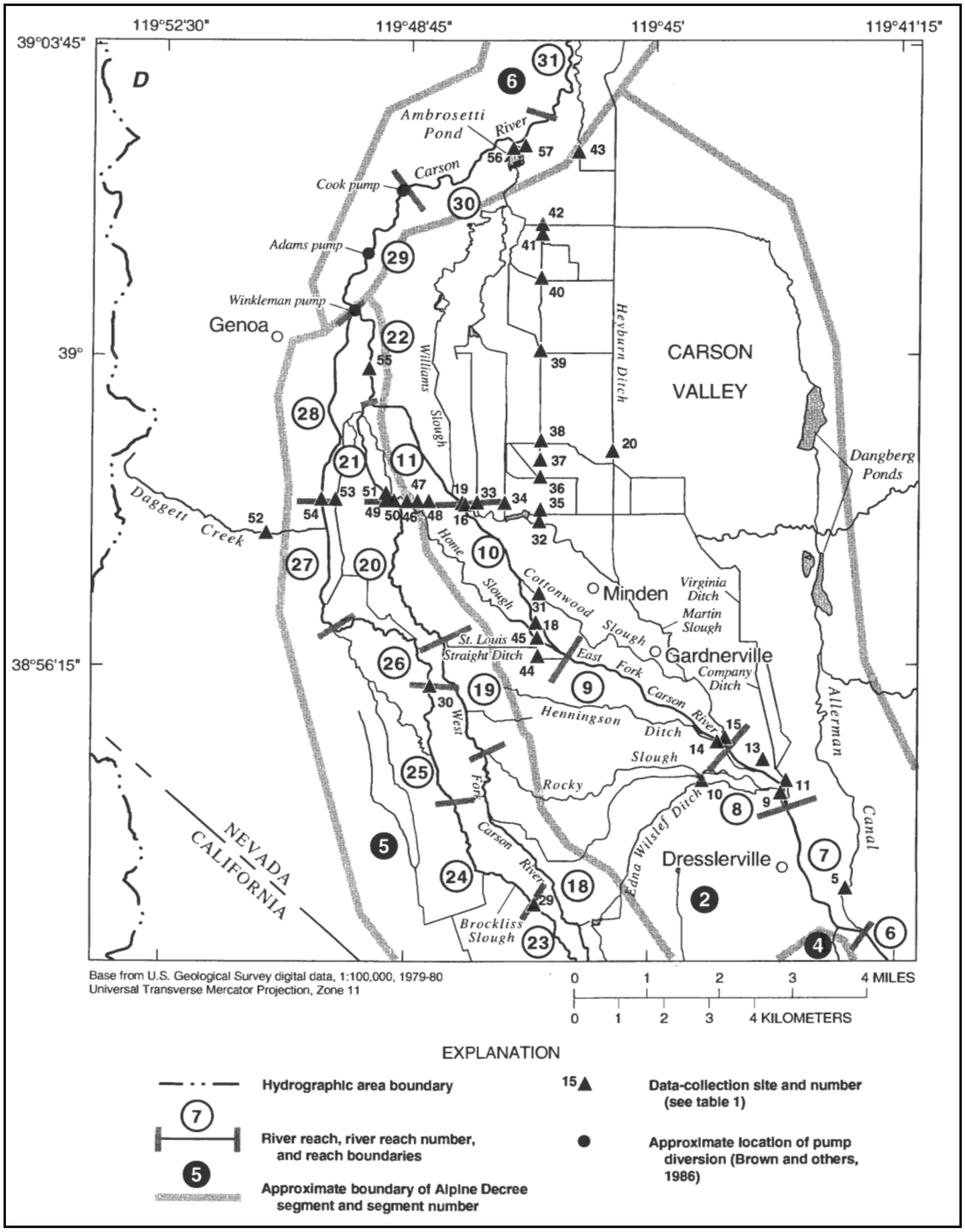


Figure 6. Map of Segments 2, 4, 5 and 6 (Hess and Taylor, 1999)

From the Fredricksburg Ditch, the West Fork flows north into Nevada and continues to supply irrigation ditches such as the Deluchi Ditches No. 1 and 2, Thran Ditch, Wyatt Ditch, Dressler Ditch and Jones Ditch. Additionally, the West Fork supplies two larger ditches, the Falke Tilman Ditch and the Company Ditch. At the Brockliss Slough "diversion" the West Fork's flow is fully committed to the Brockliss Slough, with exception to minor amounts of return flow spilling back into the old West Fork's channel shortly thereafter. Thus, the Brockliss Slough becomes the new West Fork of the river and shifts flow west of the historical West Fork, the channel of which runs mostly dry until it begins to acquire return flows from East Fork ditches, beginning with Edna Slough.

The Brockliss Slough, now the West Fork, continues to flow northwest where it feeds a maze of diversions directly and indirectly via return flow. Near its end, the Brockliss Slough splits up into an Upper and Lower reach, merges back into one course, then rejoins the Main Carson River shortly after the confluence of the East Fork and historical West Fork.

1.5.4 The Historic West Fork Post-Brockliss Slough

After the Brockliss Slough, the historic West Fork channel turns north-northwest and is characterized by low, often dry flows. Because of return flow from East Fork diversions, however, the historic West Fork does not stay that way for long. Less than a mile after the Brockliss Slough, the historic West Fork acquires its first real return flows from a combination of the Falke Tilman Ditch and the Edna Slough, a diversion off of an East Fork diversion, Rocky Slough. The Rocky Slough is the first of a few old river channels, called sloughs, which connect the East Fork and historic West Fork prior to their confluence some five miles away, southeast of Genoa (Figure 6). When the East Fork is running high due to heavy spring runoff or flood events, these sloughs help to spread the flood water out across the valley (Horton, 1997b).

Some two miles after receiving inflow from Rocky Slough, the St. Louis Straight Ditch flows into the historic West Fork. In between these surface water flows, the West Fork is acquiring significant groundwater flow from irrigation to the east supplied in large part by the Henningson Ditch. Some two miles after receiving the St. Louis Straight's inflows, the historic West Fork acquires flow from the Home Slough. Approximately a mile and a half later outside of Genoa, NV, the historic West Fork merges with the East Fork. Another one and a half miles downstream, the Brockliss Slough joins what is now the main Carson River, and the river turns northeast as it heads toward Carson City and

Eagle Valley (Figure 6). As with earlier stretches of the historic West Fork, there is significant groundwater flow into the river throughout this region.

1.5.5 The East Fork of the Carson River

The East Fork is the larger of the two forks, both in volume and in length. The East Fork's annual headwater flow averages more than three times that of the West Fork's and traverses nearly double the length (65 to 33 miles) from headwaters to confluence. Like the West Fork, the East Fork begins its journey high in the Sierras (over 11,000 feet), where it drains the north slope of Sonora Peak and the East slope of Stanislaus Peak (Horton, 1997b). From its headwaters, the river makes its way toward Markleeville, CA, the site of its uppermost headwater gage, along the way increasing its flow from numerous creeks and tributaries. From Markleeville, the East Fork flows northeast into Nevada, where soon after crossing the state line, the river receives inflow from Bryant Creek (Figure 6).

Approximately eight miles after gaining inflow from Bryant Creek, the north flowing East Fork feeds its first major diversion in the Allerman Canal, one of the first canals built in the basin, constructed in 1861 (Horton, 1997b). The Allerman Canal is the largest diversion on either fork (not counting the Brockliss Slough), averaging nearly 100 cfs at its peak in May (period of record 1984-2004; see Appendix B). Along its northerly trek toward the Danberg Ponds, the Allerman Canal picks up small amounts of flow from two tributaries flowing off the Pine Nut Mountains: Pine Nut Creek and Buckeye Creek.

Like the Fredricksburg Ditch on the West Fork, the Allerman Canal supplies a network of other canals directly and indirectly via return flows, which in turn irrigate thousands of acres of land (Figure 6). These canals eventually return varying degrees of their flows to the East Fork and Main Carson River either through direct surface return flows or indirectly via groundwater. Like other diversions throughout the basin, the Allerman Canal and subsequent East Fork ditches divert water during the irrigation season only, typically from mid-March through mid-October, with flow in March and October not as common and dependant on necessity (March) and availability (October).

After the Allerman diversion, the East Fork picks up minor amounts of flow from Indian Creek. From Indian Creek, the East Fork turns northeast, and supplies many more significant gaged diversions in the following order: Virginia Ditch, Rocky Slough, Cottonwood Slough, and Henningson Ditch. These diversions in turn supply other diversions which provide irrigation for thousands of acres of land before eventually returning a portion of their flow back to the East Fork, West Fork, or Main Carson River.

After the Henningson Ditch diversion, the East Carson encounters the St. Louis Straight Ditch, Home Slough, and Williams Slough. When the river goes on regulation these particular diversions are governed differently than many of the other diversions. The river goes on regulation when the Water Master determines there is not enough water in the Upper Carson River to serve the most junior priority. When such a determination is made, water users are notified that the river is on regulation and previously unregulated diversions are monitored. The net effect of this is such that these three diversions run significantly lower than their peak flows after the river goes on regulation and at the same time, rely more heavily on return flows. In between these diversions, the East Fork picks up return flows from diversions east of the river, notably the Cottonwood Slough and the Poleline Ditch, the flow of which is a combination of return flows from the Allerman Canal, Virginia Ditch, Martin Slough and possibly some well return flows (J. Larrouy, personal communication, 2005).

Some two miles after the Williams Slough diversion, the East Fork rejoins the historical West Fork and approximately one and a half miles later, the Brockliss Slough enters the Main Carson River.

1.5.6 The Main Carson River

From the East and West Fork Confluence, the Main Carson River heads northeast toward Carson City. Along the way, the river continues the trend of acquiring ground and surface water return flow from irrigation ditches. Approximately five miles after the confluence, flow from Ambrosetti Pond enters the river. Some five miles after that, Clear Creek enters the river. Some four miles later, the river feeds its last major Carson Valley diversion, the Mexican Ditch, before skirting Carson City and entering Dayton Valley, some ten miles after Mexican Ditch (Figure 7).

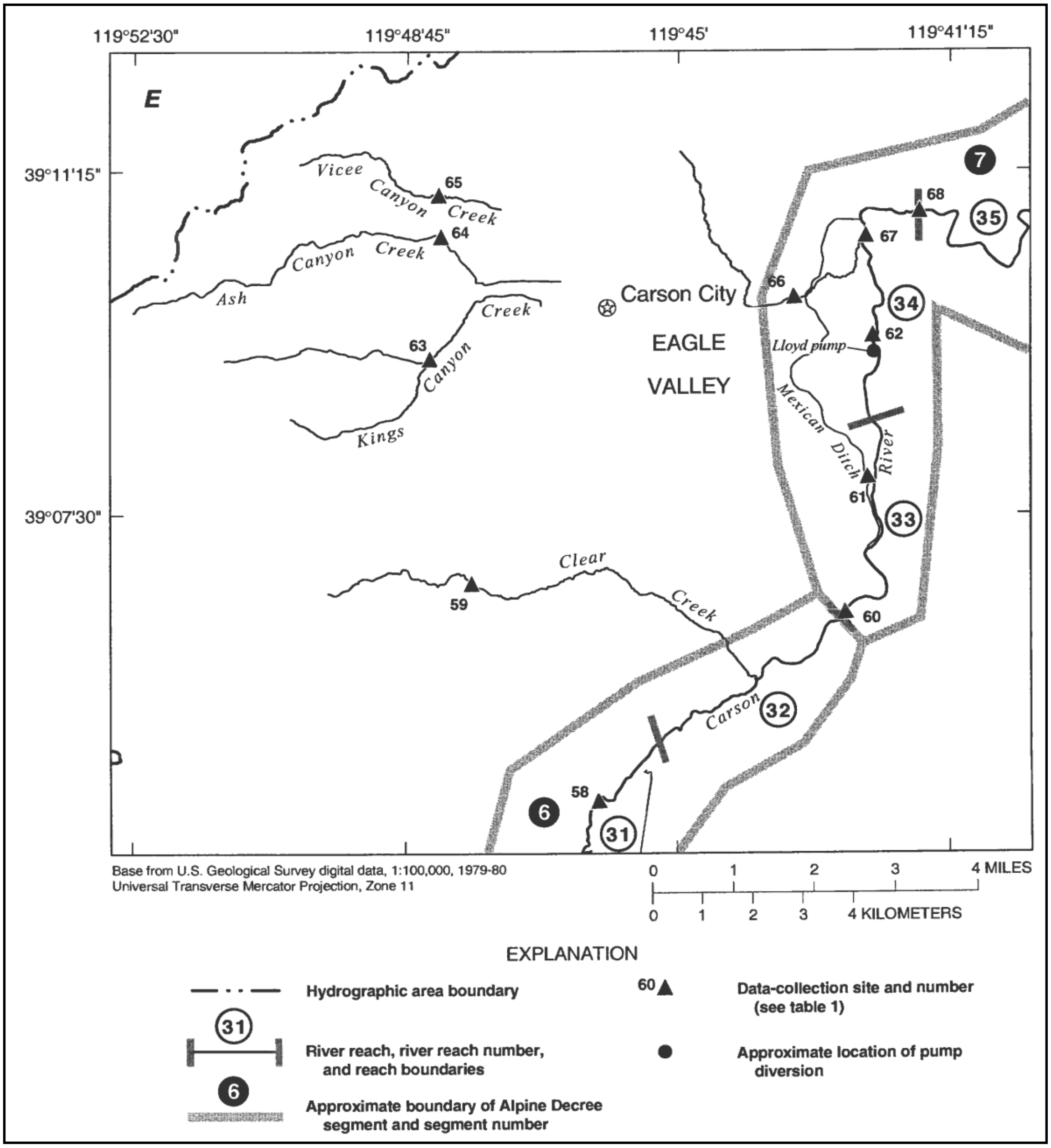


Figure 7. Segments 6 and 7 (Hess and Taylor, 1999)

The Carson River supplies its first Dayton Valley diversion, the Rose Ditch, just prior to entering the town of Dayton, NV. Two miles later is the Fish Ditch, shortly followed by the Baroni Ditch, Cardelli Ditch, Quilici Ditch, and Gee Ditch. After meandering northeast for ten miles, the River delivers irrigation water to the Koch Ditch (Figure 8).

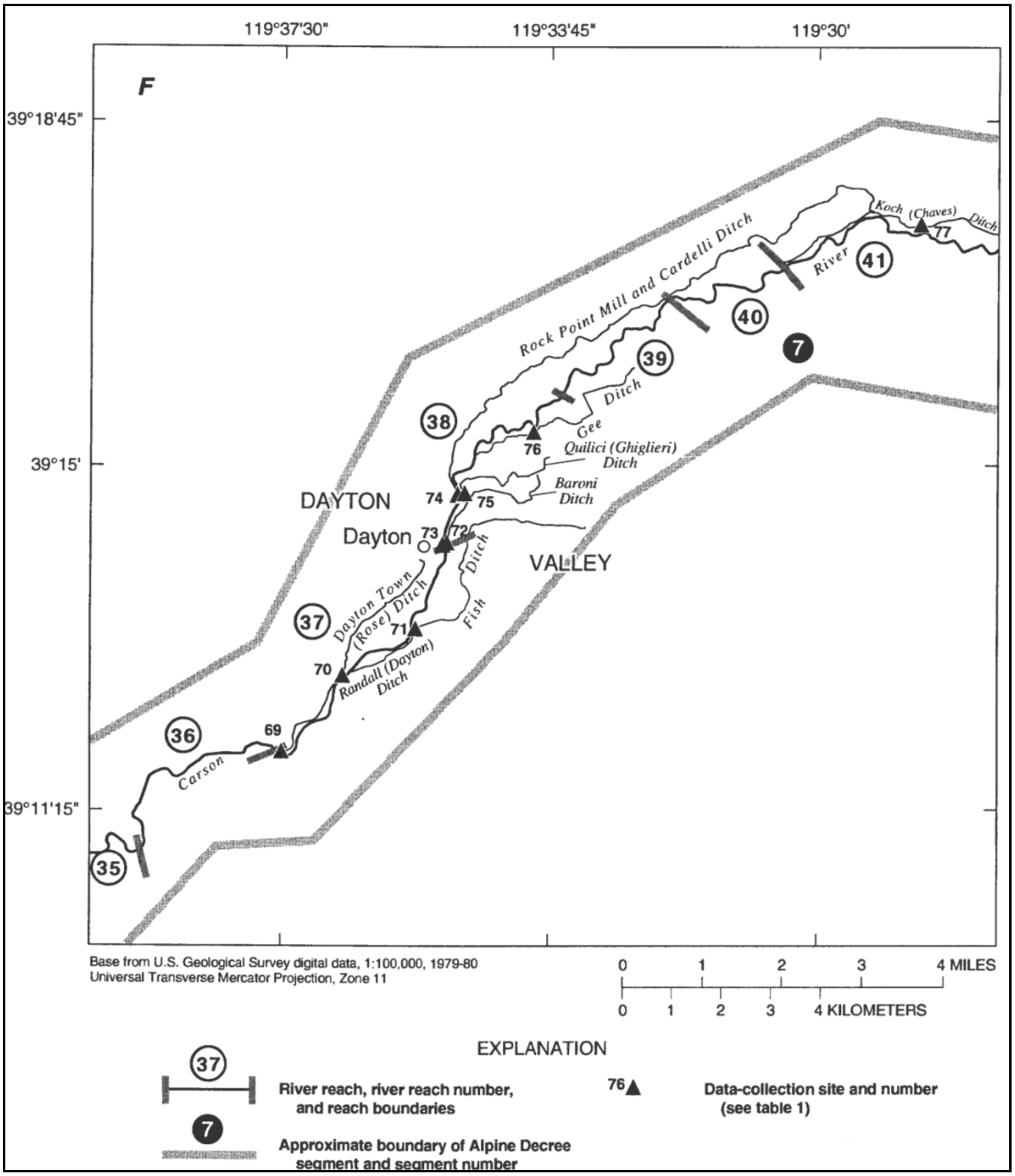


Figure 8. Segment 7 (Hess and Taylor, 1999)

From the Koch Ditch, the Carson River heads due east over twenty miles until it reaches Lahontan Reservoir in Churchill Valley. Along the way, the river delivers water to the Houghman and Howard Ditch and the Upper and Lower Buckland Ditches (Figures 9 and 10).

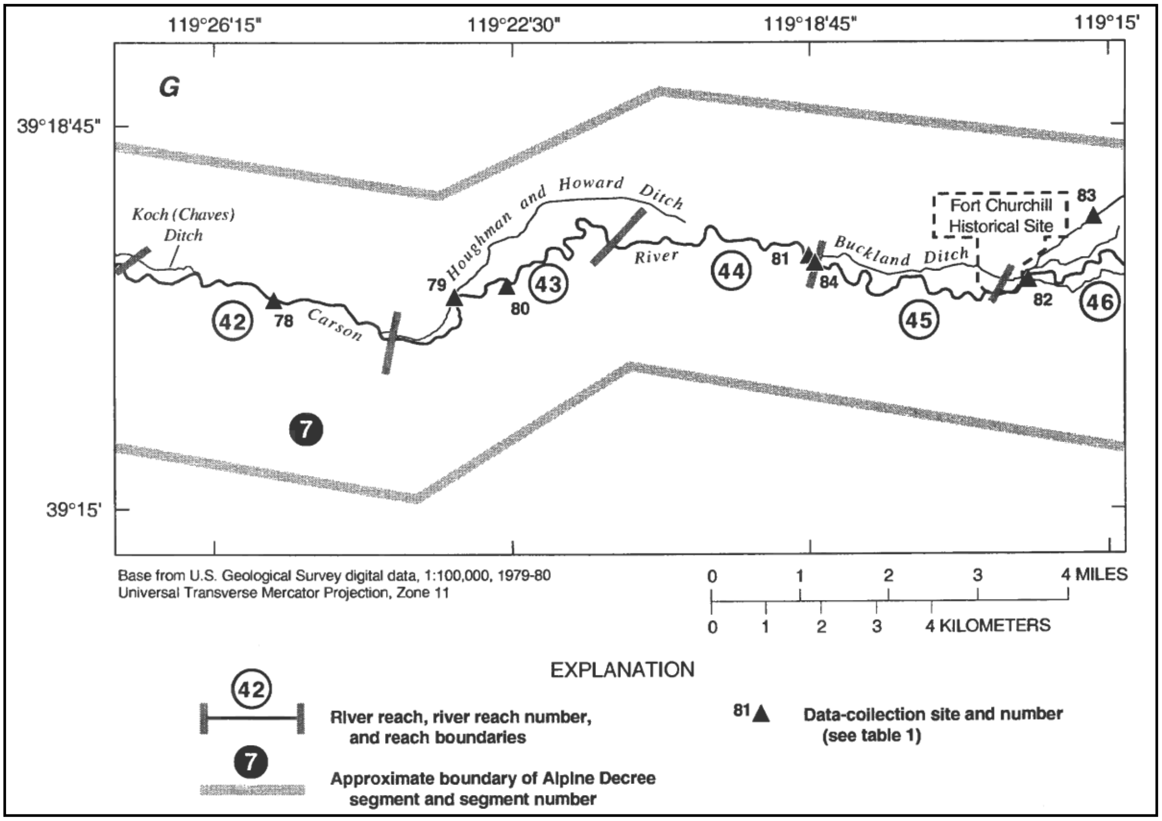


Figure 9. Segment 7 (Hess and Taylor, 1999)

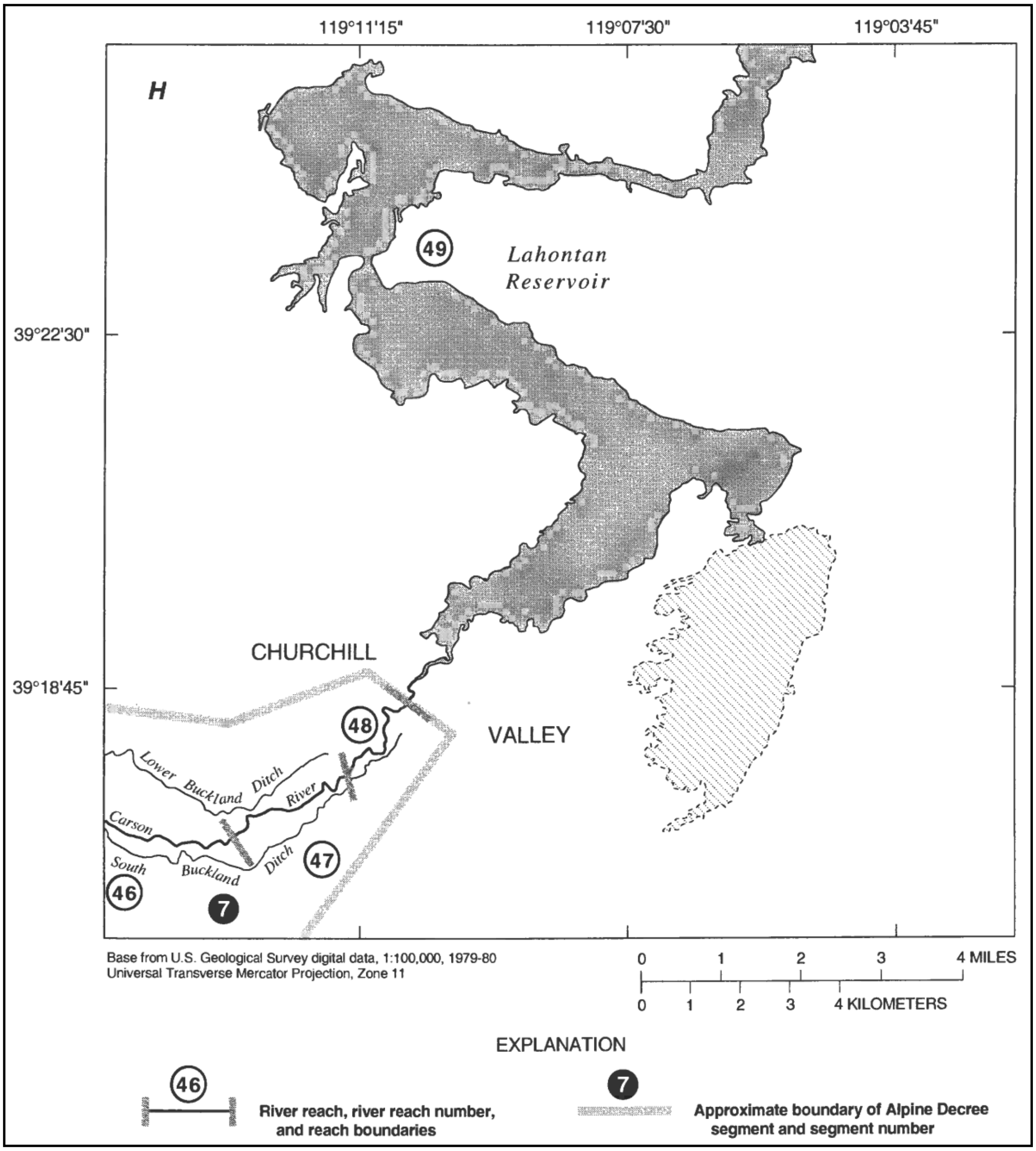


Figure 10. Segment 7 (Hess and Taylor, 1999)

1.5.7 Historical Carson River and Tributary Flows

Based on USGS gauging records, historical (1961-2003) headwater inflows of the Carson River to the valley have averaged approximately 464 cfs (average of 358 cfs for the uppermost East Fork gage and 106 cfs for the uppermost West Fork gage, See Appendices A, B). River outflows for the same time period average 415 cfs for Gage 10311000 near Carson City and 391 cfs for Gage 10312000 near Fort Churchill just above Lahontan Reservoir (See Appendix C) with year to year variability. For example, the lowest combined average annual headwater flow during this time period was 112 cfs, occurring in 1977, while the highest combined average annual headwater flow during this time period was 1,079 cfs, nearly ten times the low flow. This high year of flow occurred in 1983. In 1997, combined headwater flow exceeded that of 1983 during the months of January through April due to heavy winter precipitation, a rain on snow event in January, and an early spring runoff. However, 1983's flow was considerably higher and more sustained throughout the summer, and as such is considered the high flow year (See Appendices A, B for data).

The majority of flow in the Carson River and the various ditches and sloughs in the Dayton, Eagle and Carson valleys originate from the East and West Fork headwaters, however, there are other sources as well. According to recent studies by Maurer et al. (2004), gaged and ungaged tributaries, together with ephemeral drainages, annually contribute an estimated 37,600 acre-feet to the basin. In terms of flow, this would be a constant flow of 52 cfs or approximately 11% of the average combined flow of the East and West Forks' headwaters. Flow does not occur year round, however. Perennial stream flow is heaviest in the early spring and gradually tapers off in the summer, then increases again when winter precipitation begins to fall. Ephemeral drainages typically flow only during spring runoff in wet years or during significant precipitation events (Maurer, 2004). If this estimated streamflow is presumed to follow a similar runoff curve to that of the combined East and West Fork headwater gages (which it does not), its flow can be put in context with average, low, peak and flood (1997) combined headwater flows (Figure 11).

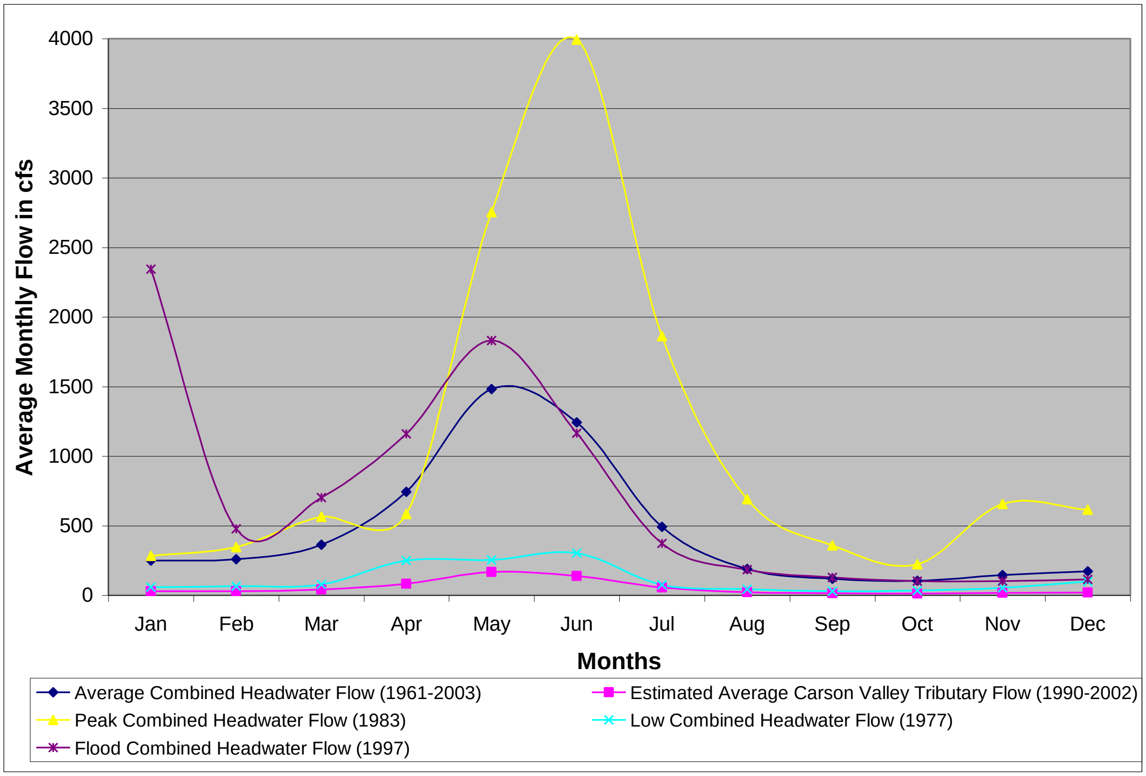


Figure 11. Estimated Average Carson Valley Tributary Flow and Combined (East and West Fork) Carson River Average, Low, Peak and Flood Headwater Flow (Gaged)

1.5.8 Groundwater Hydrology Affecting Flows in the Carson River

The success of agriculture that owes its existence to the Carson River is in large part due to the ability of the valleys where agriculture is prevalent to act as a catchment basin for surface and groundwater (Horton, 1997b). Groundwater generally moves from recharge areas in the mountains and alluvial slopes to the valley floor. In Carson Valley, groundwater follows surface contours, and generally flows from west to east toward the center of the valley, then north towards Eagle Valley. In Eagle Valley, groundwater generally flows east from the Carson and Virginia Ranges toward the center of the basin. However, in some areas of the valley, such as Clear Creek, groundwater flows directly to the Carson River (Kennedy/Jenks/Chilton, 1988). In Dayton Valley, groundwater flows from the mountain blocks toward the Carson River and then flow follows the river. In all of the valleys, where the groundwater table is lower than the stream and ditch bottoms, the surface water recharges the aquifer below. Where the groundwater table is higher than the stream and ditch bottoms, the streams and ditches act to drain the underlying aquifer (Maurer and Peltz, 1994). While there have been numerous studies addressing groundwater flow direction in the basin, such studies have not quantified groundwater flows the way the many USGS gages throughout the basin have quantified surface water flows.

1.6 Water Law, Governance, Rights, and Use

Nevada water law is based on two fundamental principles: prior appropriation and beneficial use. Prior appropriation in its simplest form means "first in time, first in right." Typically, the oldest (senior) rights on a river must be completely filled before younger (junior) rights receive any water. In practice this is not always the case, notably not on the Carson River. Beneficial use is the basis, the measure and the limit of the right to the use of water (NRS 533.035).

A fundamental tenant of prior appropriation is the doctrine of abandonment, more often described as, “use it or lose it.” In Nevada, five years of intentional non-use historically resulted in abandonment. This has recently been changed, however. Now, water rights can only be lost through voluntary abandonment.

Nevada water law, while generally based on the doctrine of prior appropriation and beneficial use, is functionally based on very specific court cases, decrees, negotiations, settlements, agreements, operating criteria, and oddly enough, the weather. The system of management is no less simple. Management operates though the state of Nevada, various watershed councils, irrigation districts, counties, power companies, Indian tribes, the state engineer, Water Masters, and individual farmers who control flow based on supply and demand. In the case of the Upper Carson River Basin, the Alpine Decree is the principle governing body of law. In matters regarding the transfer of water rights, such issues are largely governed by Nevada Revised Statutes (discussed below in Section 9.1).

1.6.1 Water Law History for the Carson and Truckee River Basins

The law governing the Carson and Truckee River Basins represents one of the most complicated systems of water law in the United States. The two basins, although not “naturally” connected prior to man-made diversions are herein considered together to give the reader context because of the rivers’ mutual support of the Newlands Project (Figure 12), one of the largest Homestead Act projects in the west.

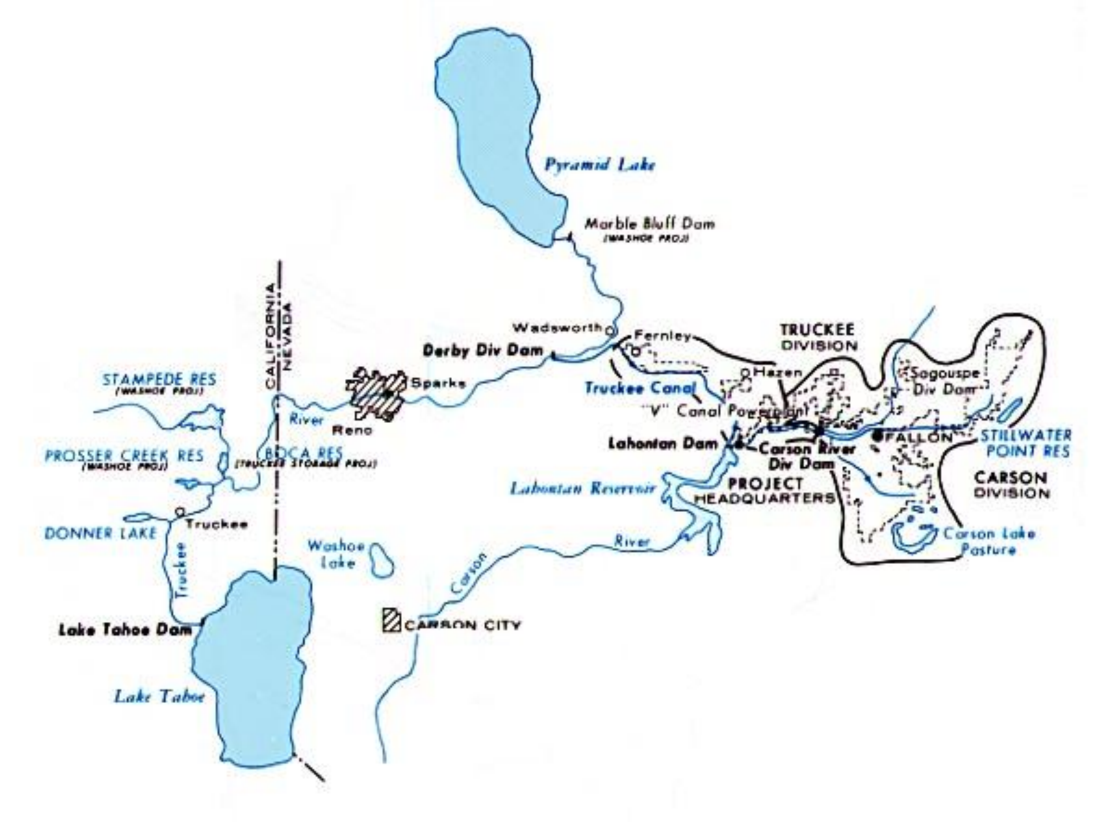


Figure 12. Map of Newlands Project, Circled in Black (TCID, 2005)

Initial conflicts over the waters in the Carson River Basin began in the 1860’s out of competition between Carson Valley farmers and ranchers and the Comstock ore processing and milling interests (Horton, 1997b). Later conflict arose from the Truckee Carson Irrigations Project (Newlands Project) in 1905 with the passage of the Reclamation Act a few years earlier. The Newlands project pitted competing agricultural interests against each other as well as against municipal and industrial interests. Years later, after agriculture demands threatened the Truckee River’s natural terminus, Pyramid Lake, the Pyramid Lake Paiutes stepped into the fray. Add some endangered species, one legal action that lasted three decades, another that dragged on for five and a half decades, and a superfund site, and you have one of the best examples of why Mark Twain quipped his famous line about water in the arid west, “Whiskey’s for drinking, water’s for fighting over.”

The first series of cases disputing water rights on the Carson River involved mills pitted against farmers. In the summers, irrigation by upstream water users often forced the mills to shut down due to lack of power (the mills used large wooden wheels to generate electricity). It did not take long for the mills to grow weary of what they perceived as farmers stealing their water. Subsequently, some of the larger mills got together and chipped in to hire a few enforcers, known as the Water Men. These men went up the Carson River and literally took out the diversion dams, thus allowing more flow in the river for the downstream mills. As time went by, the water men came to befriend some of the farmers and distrust others (the ones who continually rebuilt the dams without asking permission). This sort of relationship went on for a few years, however, discontent grew as did speculation why some farmers were “allowed” to have water and others were not. Eventually the matter landed in the courts (Danberg, 1975).

The Union Mill court cases, as they are collectively known, provided the federal courts with the opportunity to weigh on the doctrines of riparianism and prior appropriation (Horton, 1997b). The courts did in the form of the 1905 Anderson-Bassman Decree (although a later Nevada Supreme Court case repudiated the doctrine of riparianism and stipulated that Nevada water law should be based on prior appropriation because it is better suited to the region’s arid conditions). The decree established the acreage that could be irrigated pursuant to those water rights, and established a bi-weekly rotation between California and Nevada users of the upper Carson River during the months of June through October, depending on flow in the Carson River at specific points (ACRC and CVCD, 1996). For example, rotation begins on the first Monday in June, if the West Fork flow is not sufficient (less than 180 cubic feet/second (cfs)) to satisfy all rights (CDWR, 1991).

The next water dispute on the Carson was resolved by the 1921 Price Decree. This decree was the result of the failure of the earlier Anderson-Bassman Decree to specify the amounts of water that could be diverted for the acreages that were specified in the decree (ACRC and CVCD, 1996). The Price Decree only pertained to water rights in California that were served by the Carson's West Fork, and it listed a schedule naming the water user, name of the ditch, quantity available for each water right, and order of priority, all based on stream flow of the West Fork at Woodfords, the West Fork's headwater gage (CDWR, 1991).

Another dispute over Carson River water began when the Bureau of Reclamation brought suit against water users on the Truckee and Carson Rivers in order to secure water for the Newlands Project. The case, *United States v. Orr Ditch Water Company*, *et al.* was first filed by the United States government in 1913 against virtually all Nevada water users on the Truckee River on behalf of the Newlands Project farmers and eventually resulted in the 1944 Orr Ditch Decree (Horton, 1997b). By means of the Orr Ditch case and subsequently decided settlements, the Newlands Project farmers were provided the right to divert up to 1,500 cfs of Truckee River water at Derby Dam (see Figure 6 above). Then, in 1925, similar litigation was introduced against Carson River water users laying claim to Carson River water for storage in the new Lahontan Reservoir to be used by Newlands Project farmers (Horton, 1997b). That case eventually resulted in the 1980 Alpine Decree.

The Newlands Project spawned the formation of the Truckee-Carson Irrigation District (TCID). The act creating the project guaranteed a minimum of 406,000 acre-feet of water annually to the ranch areas it served. To accommodate that amount of water, the project called for the construction of a new weir at Lake Tahoe (Tahoe City), a new dam on the Truckee River about 25 miles east of Reno (Derby Dam), a new dam on the Carson River creating Lahontan Reservoir, a canal 31 miles long connecting the impoundment behind Derby Dam with the Lahontan Reservoir, and 550 miles of irrigation canals and laterals in Churchill and Lyon counties (Houghton, 1994). This project resulted in an average of 235,000 acre-feet leaving the Truckee River annually, water which would have otherwise ended up in Pyramid Lake (Horton, 1997a). This in turn resulted in the next water disputes, that of Indian and endangered species laws.

Because of the approximately 200,000 acre-feet of Truckee River water that was no longer going into Pyramid Lake, the lake began to shrink. The desiccation brought more than a few problems, the main ones being increased levels of total dissolved solids (TDS) and subsequent declines in Lahontan Cutthroat Trout and endangered Cui-ui populations. Eventually, in 1968, the Pyramid Lake Paiute Indian Tribe filed a lawsuit against the Secretary of the Interior alleging that the 1967 Newlands Project Operating Criteria and Procedures (OCAP) was allowing water to be wasted within the Newlands Irrigation Project (Horton, 1997a). That case was originally decided in the Tribe's favor, subsequently appealed by the city of Fallon, and eventually resulted in a new OCAP issued in 1988.

Under the new OCAP, the quantity of water that may be diverted from the Truckee River at Derby Dam varies each year, and is correlated to predicted runoff from the Carson River and water storage in Lahontan Reservoir. However, the Tribe was not satisfied with the final diversion allotments and filed a new lawsuit alleging the Truckee Carson Irrigation District (TCID) over-diverted more than a million acre-feet of Truckee River water from 1973-1988 and called for the water to be re-diverted back to Pyramid Lake. This in turn sparked additional lawsuits that were addressed in 1989 with the Preliminary Settlement Act that eventually culminated in the Truckee-Carson-Pyramid Lake Water Rights Settlement Act, enacted into law in 1990. This Act incorporated the 1908 Floriston Rates, the 1944 Orr Ditch Decree, and the 1980 Alpine Decree and called on the federal government to purchase some 1,058,000 acre-feet of water for Pyramid Lake (Horton, 1997a). That water, however, never came. In 1994, the first of the Truckee-Carson Settlement Negotiations began.

The Tribe had a minor victory in 1995 when, by agreement with Sierra Pacific Power Company, the Federal Water Master lowered the Floriston Rates dictated to by the Orr Ditch Decree from 350 cfs to 300 cfs. The net effect of this was the allowance of an additional 20,000-30,000 acre-feet to be stored in Stampede Reservoir (See Figure 12 above) to be used to augment spawning runs for Pyramid Lake's endangered Cui-ui sucker fish. Churchill County promptly filed a lawsuit to prevent this and a week after that, the U.S. Department of the Interior filed a lawsuit on behalf of the Tribe for the 1,058,000 acre-feet of water that was never delivered. In 1996, new negotiations between the Tribe and TCID began, only to be terminated two months later with no new agreements and little progress (Horton, 1997a).

Finally in 1996, water was purchased for Pyramid Lake. In an agreement with the U.S. Department of the Interior and the cities of Sparks and Reno, the Tribe agreed to drop all of its lawsuits in exchange for the purchase of 24,000 acre-feet of Truckee River water, which was to be stored upstream and released during periods of low flow.

1.6.2 Governance via the Alpine Decree

While all of the various court decisions and decrees pertaining to the Carson and Truckee Rivers are important in understanding the history of the Carson and Truckee Rivers and how the rivers management policies arrived at where they are today, the decree that is ultimately fundamental to understand how the Carson River functions today is the Alpine Decree. The case which was to become the Alpine Decree, *United States v. Alpine Land and Reservoir Company, et al.*, was initially filed on May 11, 1925. Water rights on the Carson River were finally adjudicated fifty-five years later via the Alpine Decree, issued October 28, 1980. With the Alpine Decree, Newlands Project landowners were finally granted formal specific water rights, to be satisfied from both the Carson and Truckee Rivers. Thus, the Alpine Decree not only governs Carson River flow, but indirectly, it governs Truckee River flow as well. To a much lesser extent two other decrees, the Anderson-Bassman Decree and the Price Decree, also play a role in Carson River governance.

The Alpine Decree set water duties for various sections of the Carson River. According to the decree, the lands above Lahontan Reservoir, of which this project is concerned, have the following water duties:

- 4.5 acre-feet/acre diverted to the canal for bottom lands
- 6.0 acre-feet/acre diverted to the canal for alluvial fan lands
- 9.0 acre-feet/acre diverted to the canal for bench lands

The decree, however, failed to specify the duty associated with each parcel of land. While some guidance has been given from the Bureau of Reclamation (see Section 1.5 above) as to bench and bottom land distinctions, water duty determination is left to the discretion of the Water Master (*US v. Alpine Land and Reservoir Company et al.*, 1980)

At first blush the above water duties may seem arbitrary, however, they are actually based on the “crop irrigation requirement” of alfalfa, as it is the dominant (and thirstiest) crop grown in the basin. The crop irrigation requirement is, as its name suggests, the amount of irrigation water required by the crop, and is defined as the difference between “crop consumptive use” and the effective precipitation required for plant growth. Crop consumptive use, or evapotranspiration, is defined as the amount of water used by vegetative growth of a given area by transpiration and that evaporated from adjacent soil or intercepted precipitation on the plant foliage. To this amount the following items, as applicable, are added: (1) irrigation applied prior to crop growth; (2) water required for leaching; and (3) miscellaneous requirements of germination, frost protection, plant cooling, etc. (Horton, 1995a).

For administrative purposes, the Alpine Decree divides the Carson River into eight different segments as follows:

Segment 1 - East Fork Carson River from the California-Nevada state line upstream to headwaters;

Segment 2 - East Fork Carson River from the California-Nevada state line downstream to confluence of East and West Forks Carson River;

Segment 3 - West Fork Carson River from the gauge at Woodfords, California upstream to headwaters;

Segment 4 - West Fork Carson River from the gauge at Woodfords downstream to California-Nevada state line;

Segment 5 - West Fork Carson River (and Brockliss Slough) between California-Nevada state line and confluence of East and West Forks Carson River;

Segment 6 - Main Carson River from confluence of East and West Forks (and Brockliss Slough) to gauge at Carson City;

Segment 7 - Main Carson River from Carson City gauge to Lahontan Reservoir. This segment is further subdivided into autonomous sub-segments:

(a) Mexican Ditch, Dayton Ditch, and the reach between Rose Ditch and Cardelli Ditch;

(b) Gee Ditch;

(c) Koch Ditch;

(d) Houghman and Howard Ditches;

(e) Buckland Ditch.

Segment 8 - The area below the Lahontan Dam (*US v. Alpine Land and Reservoir Company et al.*, 1980). See Figure 13.

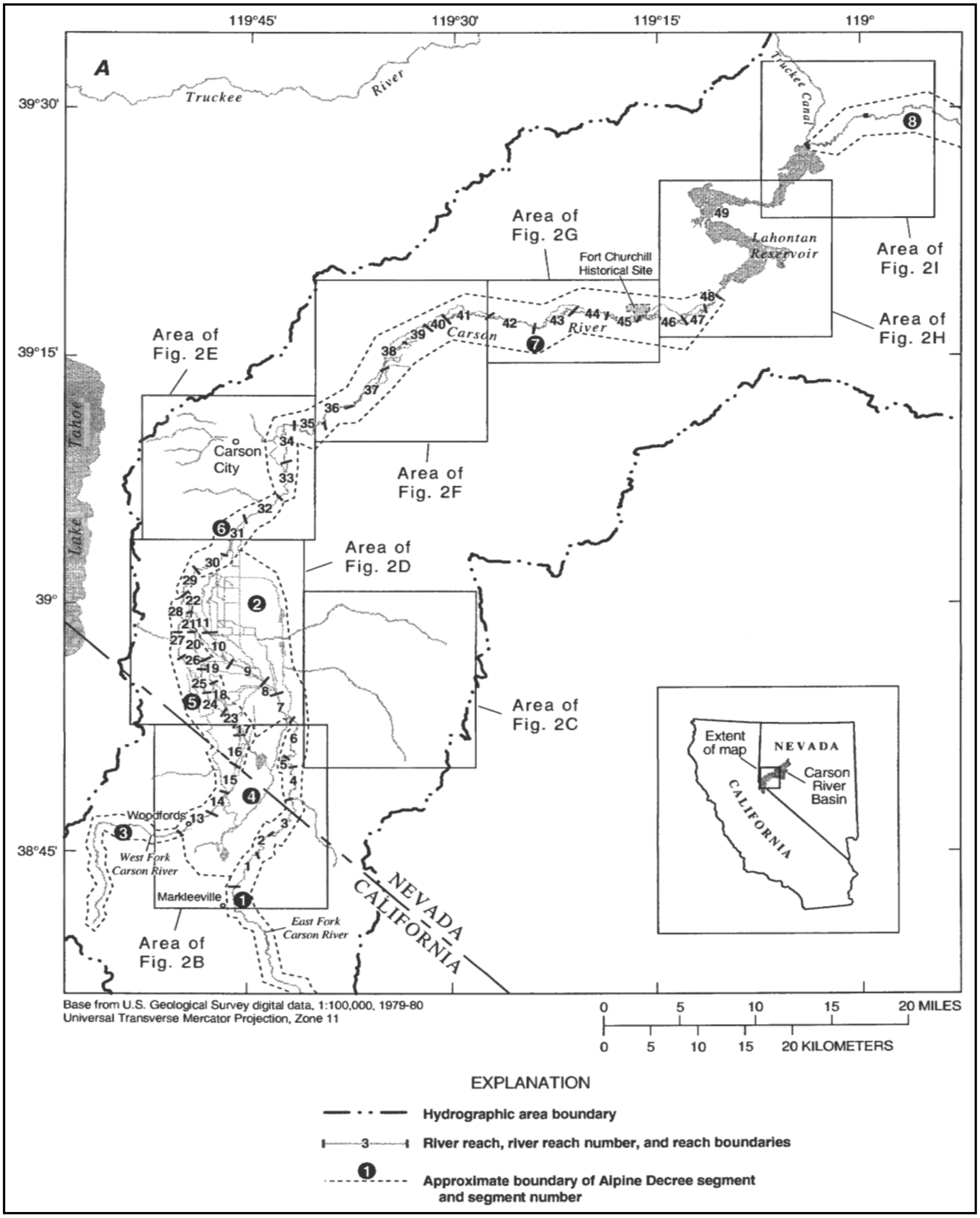


Figure 13. Segmented Carson River (Hess and Taylor, 1999)

In a “normal” year, the Carson River is governed as follows. Diversions are not monitored until the Water Master determines there is not enough water in the Upper

Carson River to serve the most junior priority. When such a determination is made, water users are notified that the river is on regulation and diversions henceforth are monitored. When the river is on regulation, each segment is treated autonomously. The high alpine reservoirs of both forks are filled out of priority due to the fact that the snow does not melt sufficiently at such high elevations to fill those reservoirs until the summer when the river flow has already begun to diminish in the valley (*US v. Alpine Land and Reservoir Company et al*., 1980). According to the State Engineer and Water Master, reservoir water can provide a portion of the duty "from any and all sources" to the land it serves (Kennedy/Jenks/Chilton, 1988). A general guide to how the Carson River is regulated according to the Alpine Decree follows (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segments 1 and 3 (Figure 5): As these segments largely consist of riparian lands, there are no relevant customs. The Water Master only regulates the release of water from mountain reservoirs (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segment 2 (Figures 5 and 6): When flow at the Gardnerville Gage reduces to 200 cfs, one third of the East Fork's flow is channeled into the Allerman Canal. Most diversions are based on a two-week irrigation interval (two weeks on, two weeks off). Some smaller canals divert only two days of the two weeks while some larger canals divert continuously (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segments 4 and 5 (Figures 5 and 6):

- Per the Anderson-Bassman Decree, starting the first Monday in June and continuing through the end of the irrigation season (October 15th), Segment 4 and Segment 5 users rotate the available water supply on a weekly basis.
- During Segment 5 week, the water is allocated via priority. During Segment 4 week, Segment 5 junior appropriators who did not get direct flows during Segment 5's allotted time are allowed to use return flows from Segment 4.

- Water stored in Mud Lake Reservoir (Figure 8) can be released to downstream users in exchange for direct diversions that would otherwise go to those downstream users.
- During times of short supply in the Brockliss Slough (Figure 9), water use is rotated among the three oldest priorities with a second rotation being observed among the other priorities.
- Some rights that appear to be served with West Fork water are actually served via East Fork return flow that flows into the West Fork.
- Water diverted out of the East Fork via Rocky Slough and into Edna Ditch (Figure 9) and other small ditches is used to irrigate the lands between the two forks (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segment 6 (Figures 6 and 7): Diversions in this segment occur by pumping directly from the river the amount that is sufficient to satisfy the particular priority. Because of the high cost of regulation in comparison to benefits derived, the Water Master makes no attempt to regulate this segment unless a controversy arises (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segment 7 (Figures 7-10): Due to the intermittency of the river's surface flow, this segment is regulated in autonomous sub-segments (*US v. Alpine Land and Reservoir Company et al.*, 1980).

Segment 8: Located downstream of Lahontan Reservoir, not relevant to project at hand.

As one can see from the above segment synopsis, there is a significant human element to the way the Carson River operates. Thus, the model described in this report does not specifically contain code that attempts to mimic all of the above governance. Rather, the model codes only some of the major facets of the Alpine Decree. The rest of the model is based on relationships between various portions of the river that intuitively reflect the governing logic so that indirectly, the model simulates the behavior of the Alpine Decree on the river's hydrology.

1.6.3 Water Rights and Water Rights Transfers

The majority of water rights in the project area of the Upper Carson River Basin are for surface waters of the Carson River that were established by the Alpine Decree described above. When decree rights are correlated to acre-feet, total allowances from the Alpine Decree total approximately 290,000 acre-feet, excluding California riparian rights. In addition to Carson River water rights, there are approximately 22,000 acre-feet of water rights from springs and creeks in the basin. Additionally, there are approximately 83,000 acre-feet of groundwater rights (Kennedy/Jenks/Chilton, 1988).

In recent years, there has been a trend along various portions of the Carson River towards purchasing water rights for retirement and/or conservation purposes, acquiring riparian conservation easements, and in general, restoring/enhancing the river corridor. These actions have been taken on by various public and private actors, notably the Nature Conservancy, the Carson Water Subconservancy District (CWSD), and various Nevada state agencies.

For example, since the early 1990s over 35,000 acre-feet of water have been collectively purchased by the U.S. Fish and Wildlife Service, the State of Nevada, the Bureau of Indian Affairs, the Nevada Waterfowl Association, and the Nature Conservancy in an effort to maintain approximately 25,000 acres of wetland at Stillwater National Wildlife Refuge outside of Fallon (R. Grimes, personal communication, 2005).

In 1999, the Nevada Legislature passed legislation that directed a program be established to purchase and retire water rights from 6,500 acres in the Newlands Project, the large Bureau of Reclamation project east of Lahontan Reservoir that receives water from both the Carson and Truckee Rivers. To date, over $15 million has been dedicated to this program, with $9 million coming from the federal government, $4 million from the State, $2.5 million from Sierra Pacific Power Company, and $100,000 from Carson Truckee Water Conservancy District (CWSD, 2005). Water rights have been retired from approximately 3,300 acres. A vast majority (3,100 acres) of these 3,300 retired acres received their water rights from the Carson River, while the other 200 acres were water righted from the Truckee River (P. Pollyea, personal communication, 2005).

In 2000, the Nature Conservancy secured a riparian conservation easement along a three mile section of the Carson River south of Genoa by partnering with the Timken-Sturgis Foundation to purchase the River Fork Ranch. In 2002, Nevada voters approved a bond measure called the *Nevada Clean Water, Parks and Wildlife Bond*, that has the capability to generate up to $200 million in support of natural and cultural resources across the state. The bond designates the Division of State Lands as the state agency that administers the funds. A 50% match is required from the private sector for any project. A generous donation of $750,000 by Mr. Don Bentley in 2004 to the Nature Conservancy for a conservation easement on 1127 acres of Kirman Field, a parcel owned by Mr. Bentley, has jumpstarted this public-private partnership on the Carson River (Nature Conservancy, 2005).

In addition to the Nature Conservancy, the CWSD has been an active player in helping to restore the Carson River. Together, with the help of other agencies and organizations, CWSD is involved with numerous projects that aim to reduce stream bank erosion, reestablish flood plain connections and riparian vegetation, increase habitat, eradicate the invasive species Tall White Top, and in general, work toward long term solutions that improve water quality (CWSD, 2005).

1.6.4 Water Use in the Carson River Basin

By far the largest user of water in the greater Carson River Basin is agriculture, where approximately 38,000 acres of cropland and meadowland are irrigated (ACRC and CVCD, 1996). Admittedly, this figure is nearly ten years old as of this writing. However, the fact that some agricultural lands are being taken out of production to make way for subdivisions and other water rights are simply not being used is being mitigated by the fact that there are some new lands being irrigated as well, notably by Bentley Agrodynamics near the airport in Carson City (E. James, personal communication, 2005). Thus, while 38,000 acres of land is not a 100% accurate assessment, it does afford the reader a reasonable estimation of the current state of affairs in the basin. The proportion of cropland and pastureland for the approximate 38,000 acres of agriculture is roughly equal. For example, in 2002, 31,000 acres of land were irrigated in Douglas County (the county with the most agriculture in the Upper Carson River Basin), 52% being harvested cropland and 48% being rangeland (US Department of Agriculture, 2004).

In 1995, irrigation accounted for 93% of all water withdrawals in Douglas County (Horton, 1995a). However, the current percentage is likely less than 93%, and the percentage will likely continue to decrease for the near future as the trend of encroaching urbanization and the transfer of water rights to other uses, namely municipal and industrial, is causing the level of irrigated lands to decline while other water uses are on the rise (NDWR, 1996). Indeed, it is this very trend that is one of the driving forces behind the many studies of the Upper Carson River Basin as stakeholders planning for the future grapple to understand and predict the environmental and agricultural ramifications of various scenarios that would enable growth to continue in the basin.

1.7 Current Study Needs

As discussed in the previous sections of this report, the Carson River Basin is facing increasing demands on its land and water resources due to increasing populations and its associated land development. A large portion of the land within the Carson River basin that is desirable for the development of housing and industrial uses is land that has been traditionally used in the production of agricultural products. In addition, surface water rights have been fully appropriated within the basin for nearly 100 years, and groundwater rights have been fully appropriated for over 30 years. Thus, development within the basin cannot be supported through the development of new water resources; rather the transfer of water from one economic use to another, or the development of efficiencies in the current water resources infrastructure throughout the basin must support it. However, any alteration in the use of land or water within the Carson River basin will potentially impact the amount and timing of flows within the Carson River. In addition, within sections of the Carson River, water quality standards are not in attainment. These water quality conditions are highly interrelated to flow conditions in the river. Hence, any change of land or water use within the Carson River watershed could also impact water quality conditions within the river. Therefore, to be able to predict the impact that proposed changes in land use and modification of the basin’s hydrologic condition will have on hydrologic and water quality conditions in the Carson River, water resources and land use planning should be done in an integrated fashion for the entire watershed. Planning at the watershed scale will allow for an examination of the cumulative impacts of development, water transfers and proposed modification to the hydrologic regime on flows and water quality in the Carson River. In addition, this planning exercise should be developed in an inclusive process, utilizing a planning tool that enables a consensus building planning environment and scientific process. Embracing the principle of inclusiveness will allow for a wide variety of stakeholder interests to be included in the planning process, which in turn will lead to the development of more robust watershed plans.

To enable this planning effort for the Carson River Basin this study develops a watershed scale Water Resources Planning Tool that can display the interaction between proposed development and hydrologic modification activities, and the impacts these activities could have on hydrologic conditions, water resource availability within the Carson River Watershed. The purpose of such a tool is two fold. First the tool can be used by a variety of agencies to help determine the viability of proposed plans based on their predicted impacts to a variety of stakeholder interests within the basin. Second, the tool can be used to aid in educating stakeholders on the impacts of development and hydrologic modification activities on water resources availability and water quality within the Carson River.

The remainder of this report documents the mathematical approaches used to predict the hydrological behavior of the Carson River Watershed, and the development of the user interface to enable the Water Resources Planning Tool to be used most effectively by water resources planners and managers within the Carson River Watershed.

2. Development of Planning Tool

2.1 Modeling Water Resources in the Carson River Watershed

Many of the ditches and sections of the Carson River within the Carson Valley are "gaining" reaches, meaning they run dry for extended periods and then begin to flow seemingly out of nowhere. A casual observer on the surface of the valley floor would likely be baffled by this sort of behavior, as the underlying reasons for the abruptly appearing flow would be elusive. If, however, the observer was able to view below ground, the process would not be as mysterious. The underground observer would see a constant flow of groundwater originating from the eastern face of the Carson Range of the Sierra Nevada Mountains, with less significant flow stemming from the Pine Nut Mountains to the east. As the snow begins to melt in the spring, the observer would see a wave of slowly moving water arrive, causing a giant aquifer under the valley to rise. Over time, the observer would see the water table rise above the depth of many of the ditches. It would then become apparent to the observer that the aquifer, like a lake, is overflowing and simply reaching equilibrium with its surroundings.

While this process of groundwater recharge, flow, and discharge is relatively simple to grasp on a macro level, the actual quantification of such flow and the relationship of the specific interactions of individual ditches is far more difficult, if not impossible to quantify on a micro level. The project at hand, modeling the Carson River from its headwaters to Lahontan Reservoir, does not set out to perform the impossible. Rather, it is the purpose of this project to create the framework for a model that correctly mimics the fundamental aspects of the system, and allows for changes in the system to be predicted with quickly obtainable results. This framework will be described as two inter-related elements. The first element being a description of the development of the mathematical relationships used to predict the response of the Carson River to future land development and water management scenarios. The second element being the description of the interface that allows Carson Watershed Decision makers to utilize the tool for creating and analyzing these future scenarios.

2.1.1 System Dynamics Modeling Approach

System dynamics (SD) software was first introduced in the mid eighties and has since been gaining popularity amongst a variety of users. SD software is simple enough for users unfamiliar with it to operate, and sophisticated enough to enable modeling of the most complicated of issues. SD software uses icon based building blocks; the most basic forms being *stocks* and *flows* (Figure 14). The specific SD software used in this study is called Stella® (ISEE systems). *Connectors* (the red lines) connect these stocks and flows. *Converters* regulate inputs and outputs by defining external inputs to the model through the calculation of mathematical relationships or by serving as the guide for graphical relationships.

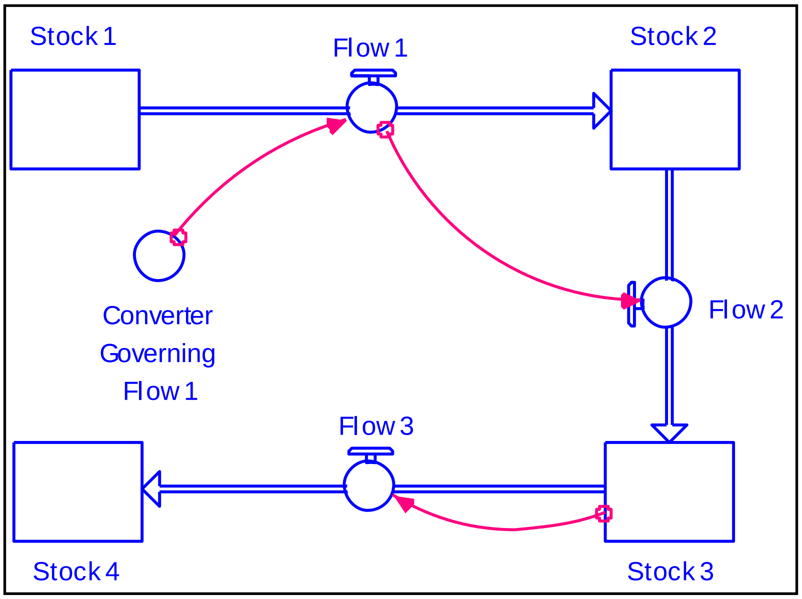


Figure 14. Example of Stella Components and Interactions

Stocks, as shown above, can serve as reservoirs (Stocks 1 and 3) with their initial values defined. Stocks can also serve as mere conduits, allowing flow to freely pass through them (Stock 2). Flows can be governed by converters (Flow 1), flows can move from one flow to the next (Flow 1 to Flow 2), or flows can move to and/or from a stock (Flow 2 to Stock 3 and from Stock 3 to Flow 3).

Streamflows and Diversions

The most common interaction of stocks, flows and converters is a diversion off of the river. Figure 15 provides an example how these components might interact within the model in a typical streamflow and diversion setting.

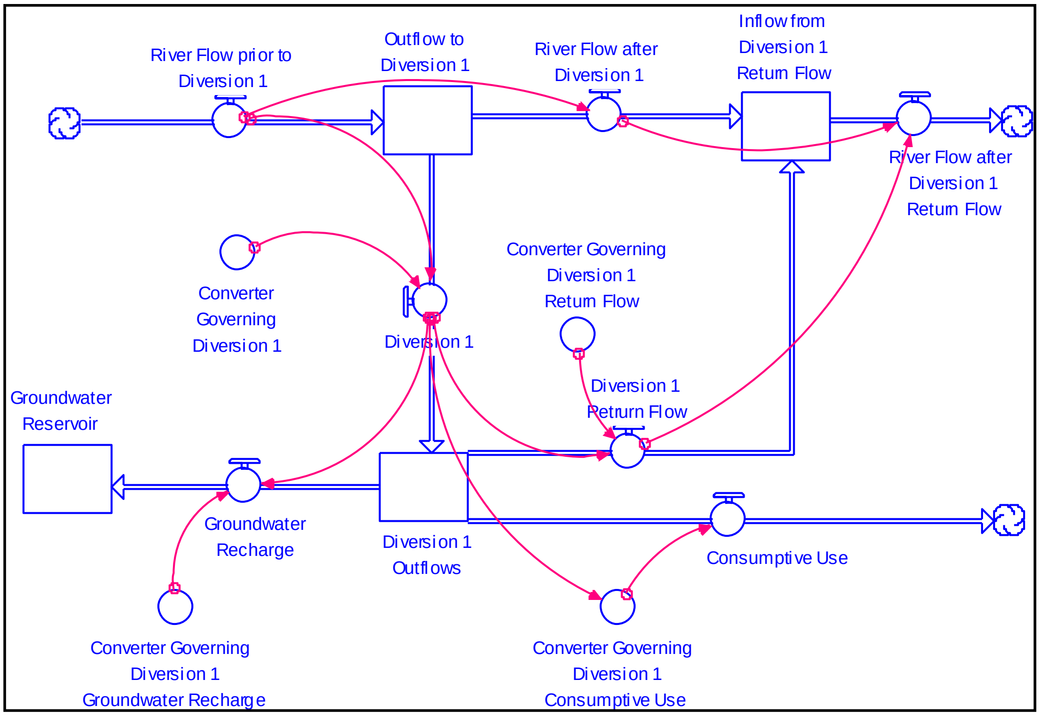


Figure 15. Example of Stella Interactions in a Typical River Diversion

In the above example, flow originates from the cloud in the upper left corner. Here the cloud represents the fact that this is a snapshot of a portion of a hypothetical model. In SD terms, the cloud is considered an unlimited reservoir (stock). A portion of flow is diverted via Diversion 1. The timing and amount of the diversion is regulated by the converter. Converters also regulate the amount of the diversion that is consumed by the crops (consumptive use), returns to the river (return flow) and that flows into the aquifer below (groundwater reservoir). Flow after the diversion would be the original flow minus the diversion plus the diversion's return flow. In the actual model, the converter governing the diversion could be a set of three or more converters and could look something like Figure 16.

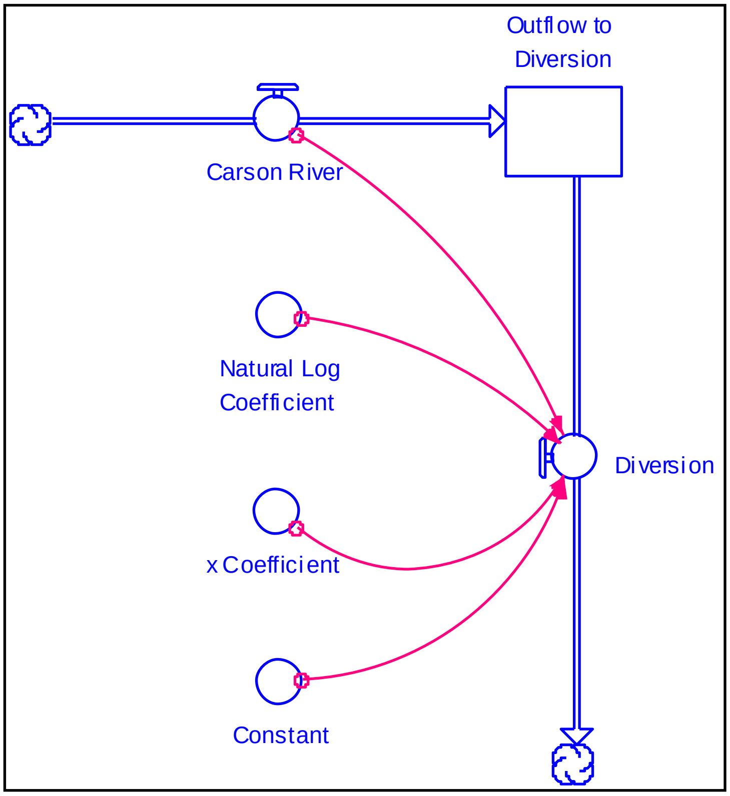


Figure 16. Example of Diversion Converters

Here, if the above were an actual diversion in the model, historical data would have been used to create a relationship between flow in the Carson River and the diversion using linear and non-linear regression analysis. Regression analysis, in general, is the process of finding a relationship that best predicts the general trends of your data. One way to measure the effectiveness of these relationships is by determining the R^2 value. $R^2 = 1-[\sum(Yi-Yi')^2 \ / \ \sum(Yi-\overline{Y})^2]$ where Yi represents an independent data point value, Yi' represents the value obtained when the independent coordinate of this data point is input into the relationship formula, and $\overline{Y}$ represents the mean Yi value.

R^2 values have a range of 0 to 1. An R^2 value of 1 implies a perfect fit. That is, the independent variable, x, accounts for 100% of the variation in y. On the other end of the scale is an R^2 of 0. This implies that all of the variation can be explained by the mean, and thus, there in no correlative relationship between x and y, and one is better off simply using the mean. For example, an R^2 value of 0.87 tells us that 87% of the variation can be explained by the given trend line. Figure 18 provides a visual representation of this a relationship and resultant R^2.

In an attempt to simplify and keep a level of consistency to this aspect of the model (diversions), the choice of regression analysis was limited to linear or natural log, with the independent variable being flow in the diversion ditch and the dependent variable being either flow in the river prior to the diversion or flow in another ditch that fed the upstream diversion. The model is based on a monthly time step using average cubic feet/second (cfs) for monthly values. Thus, if the above snapshot were part of a year long simulation of predicting a diversion from the river, each converter pictured above would have twelve individual values that collectively dictate the flow equation for the twelve different months. In the months of November through February all values would be zero, as typically diversions occur only mid-March through mid-October. During the irrigation season, the individual values for the various converters would be based on the best relationship attained through regression analysis.

Other factors also affect flow, notably losses due to unknown diversions, evaporation, transpiration due to riparian habitat, and aquifer seepage. Some hydrologic or ecologic models have components within their models that govern these elements on an individual basis. Those types of models have different objectives than this model. This model is a systems model, meaning these factors are inherently represented within the model relationships. Because this model's objective is to aid policy makers by running scenarios geared toward changing flow regimes as opposed to, say, quantifying evapotranspiration, this model takes a macro rather than a micro approach with respect to variables such as evapotranspiration et al.

As was stated above, the relationship is limited to either natural log or linear functions. Defining which function determines the best relationship is accomplished by using a visual field analysis in conjunction with comparing R^2 values, all while attempting to understand the hydrologic mechanisms that govern the relationship, and determining whether the relationship makes sense with respect to those mechanisms. Visual field analysis is the process whereby the data in question is integrated into a graph, thus allowing the viewer to quickly gauge the strength of one or more relationships.

For example, the equation governing the flow titled “Diversion” in the above example would look something like the following:

$$(\text{Nat\_Log\_Coef}*\text{LOGN}(\text{River}))+(\text{x\_Coef}*\text{River})+\text{Constant}$$

In the above equation, the function LOGN takes the natural log of the number in parenthesis following LOGN. The different converters would vary on a monthly basis, thus allowing the diversion to be controlled by flow in the river. Obviously the above hypothetical diversion portrays a relatively simplistic view of what is occurring. In reality, the closest gaged portion of the river that the diversion is being correlated to is miles before the diversion. In between could have been several gaged and/or ungaged inflows and outflows. To correlate diversion flow to river flow often requires building a new data set for the Carson River that represents flow adjacent to the diversion. This is accomplished by starting with the closest gage on the river and adding/subtracting known and/or estimated inflows and outflows from that gage. Governing logic can also become more complex through the use of IF THEN ELSE logic, which in this model was typically used to establish an upper or lower limit on diversions

Taking a few examples from diversions that best illustrate these model elements may provide the reader with far more insight than words can aptly describe. The graphs that follow (Figures 18 and 19) are from C84 Rocky Slough in July (Figure 17).

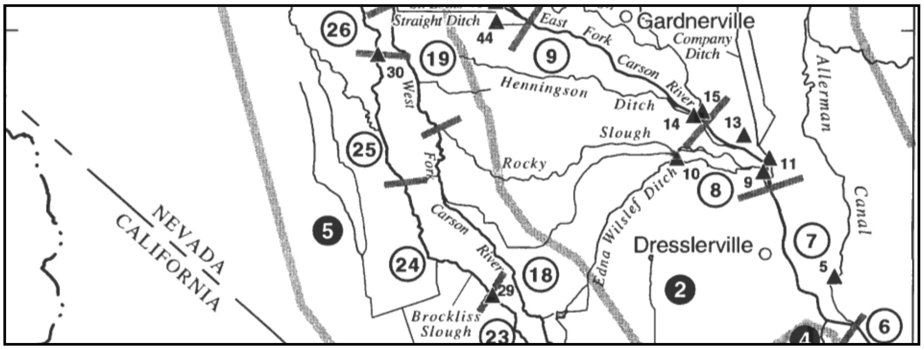


Figure 17. Rocky Slough Diversion

Here, the goal is to find the best relationship that exists between how much flow is being diverted into Rocky Slough and how much flow is in the river just prior to the diversion. The purpose of determining this correlation (and others) is so that in the model, if flow in the river prior to Rocky Slough is altered (because of another diversion, water transfer, drought, climate change scenario, etc.), the model accurately predicts how much water will flow in Rocky Slough.

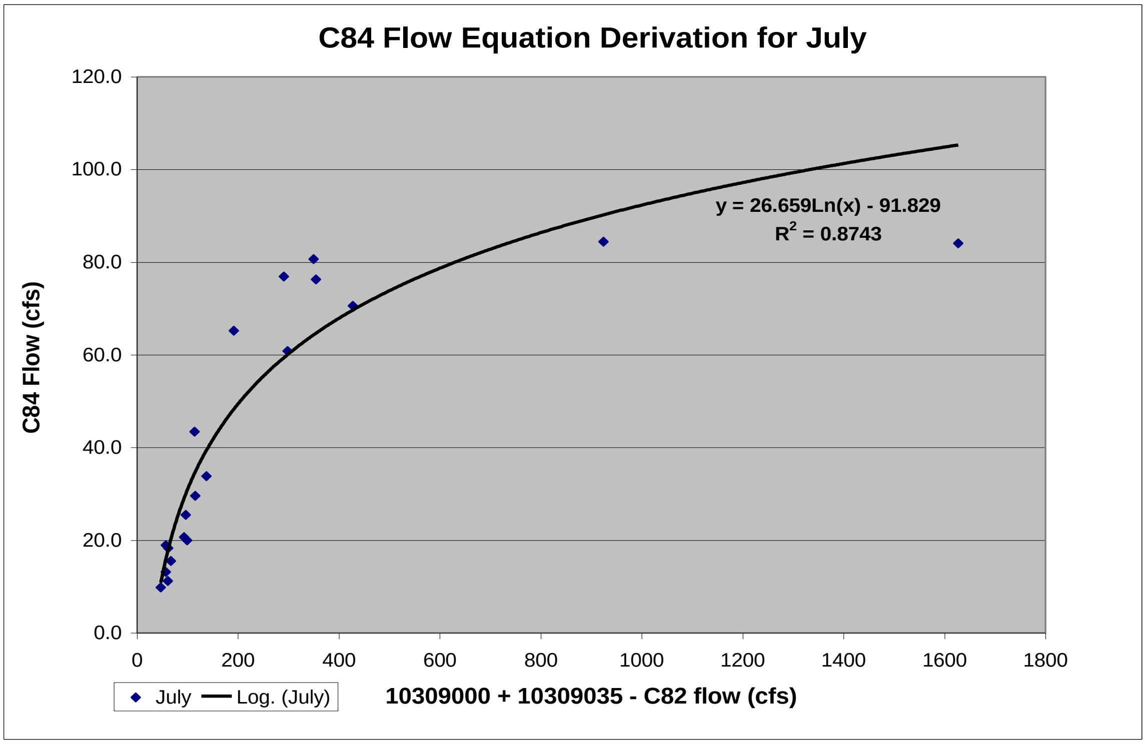


Figure 18. C84 Rocky Slough July Equation Derived via a Natural Log Trend Line

The period of record for the data is 1984-2004. The x axis represents an approximation of West Fork Carson River flow at the diversion. Flow just prior to the diversion is estimated by starting with the closest upstream gage's measurement for July on the river (here, Gage 10309000), adding inflows between Gage 10309000 and the Rocky Slough diversion (here, Gage 10309035 Indian Creek average flow for July) and subtracting outflows (here, C82 Allerman Canal average flow for July). The y axis is Rocky Slough. The first graph, Figure 18, represents a trend line derived via a natural log relationship. The second graph, Figure 19, represents a trend line derived via a linear relationship.

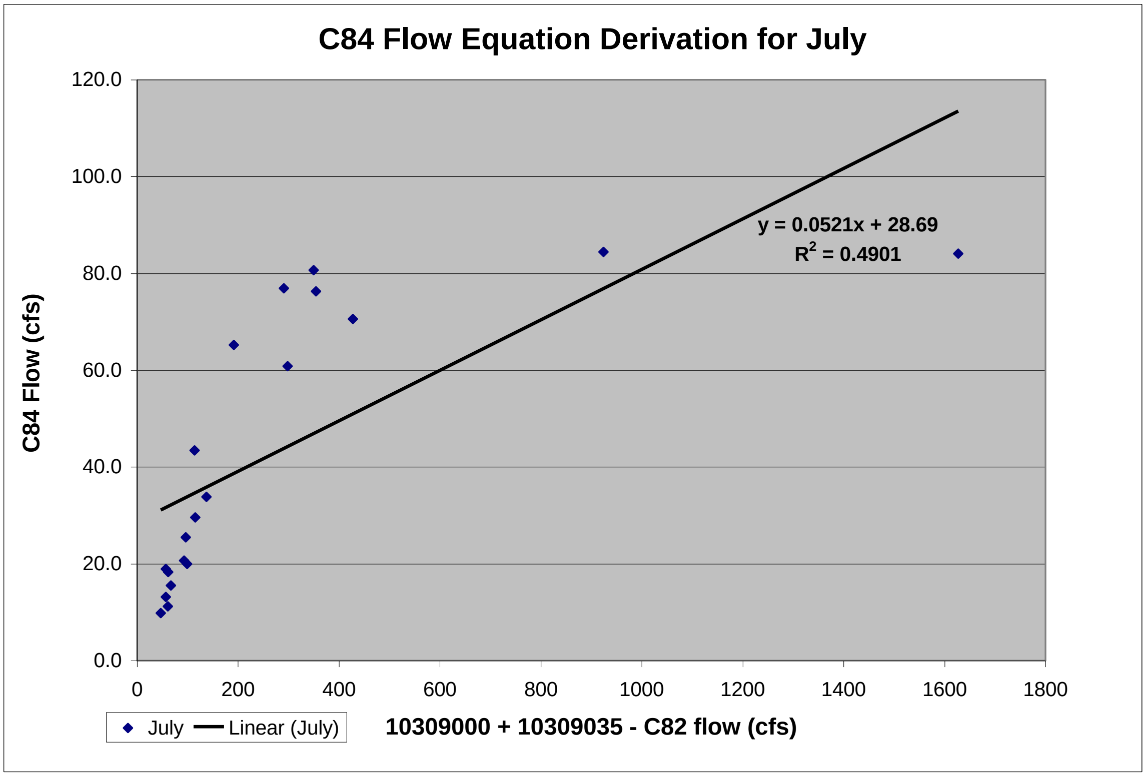


Figure 19. C84 Rocky Slough July Equation Derived via a Linear Trend Line

Obviously, for this particular diversion in this particular month, the natural log relationship provides the better fit, and thus, when used in the model, it will more accurately predict the results of the scenario the model's user is running (another diversion, water transfer, drought, climate change scenario, etc.). Intuitively, the natural log relationship fits most diversions well as the nature of the curve reflects both physical and governing characteristics of the river. Natural log curves can generally be characterized as having sharp rates of increases quickly followed by a more gradual curve that eventually levels out. From a physical perspective, if there's little flow in the river, the diversion will take up most, if not all of that flow (sharp increase). As the ditch nears capacity, it doesn't matter how much flow is in the river, the ditch simply cannot handle any more water (leveling out). From a governance perspective, flow may become limited not because of the ditch's capacity, but because the water righted limit is reached. If the relationship follows a linear relationship, this likely means that the ditch's capacity or water righted limit is not coming into play.

Not only does the natural log relationship intuitively make sense, here it is evident from the difference in R^2 values and the visual fields analysis as well. Here, 87% of the variation can be predicted by the natural log trend line versus only 47% by the linear trend line. A visual inspection of the graph further reveals which fit is better. The linear trend line overestimates nearly one third of the data points and underestimates nearly another third. Alternatively, the natural log trend line only significantly overestimates the abnormal precipitation year that was 1995 (abnormally heavy late spring snow in conjunction with abnormally cold spring temperatures in the mountains caused the runoff to occur much later and thus be far more sustained during the summer). Realistically, this sort of abnormality is not the sort of significant event that will be guiding water policy in the watershed.

Return Flows and Consumptive Use (Stream Losses)

Many of the ditches and canals that spread the Carson River's waters throughout Eagle, Dayton, and Carson Valley rely to some extent on return flows. Some rely entirely on return flow, notably the historic West Fork after the Brockliss Slough diversion. As was discussed above, when the irrigation season begins, the valley is largely flooded. This in turn causes the water table to rise. Where the ditches are dug or cut deep enough, they perform the same function as streams flowing out of a lake. To accurately portray this important component of the system, there must be a mechanism in the model that mimics this process. While groundwater flow direction is for the most part known in the Upper Carson River Basin, the amount of flow has not yet been quantified.

One way to estimate groundwater flow is to back engineer its flow. For this sort of systems model, back engineering a flow regime entails following certain steps. First, the model is built with the infrastructure that has the capability to transport groundwater. With the infrastructure in place, all groundwater flows are set to zero. Next, simulations of the model are run to determine where flow is lacking or in surplus. At this stage, it is important to rule out other possibilities for the discrepancies such as overlooked diversions, overlooked inflow from tributaries, inadequate or surplus crop consumption, etc. Once one is reasonably sure that the remaining surplus/deficiency is due to groundwater, attempts are made to determine the correct groundwater relationships and mechanisms that increase flow to the deficient areas and/or decrease flow where it is excessive.

This last step must be done holistically with one eye concentrating on the individual groundwater flow and the other eye thinking holistically. The connections must be logical from a hydrological standpoint or the goal of the model is lost. That is, simply building a model that creates the right output from a given input is not good enough, as when new, previously unseen, scenarios are run by the model, an accurate result is not likely to be produced for that situation. The model must actually represent the system to the greatest degree that it can. Part and parcel to achieving this representation is finding a balance between model specificity and complexity. Meeting all of these goals involves following the principles of Occam’s razor, which generally states that one should not increase, beyond what is necessary, the number of entities required to explain anything.

The model described herein sets out to do just that. Where return flow is known or assumed to occur, a pathway for that return flow exists in the model. Typically, return flows are a mixture of both surface and subsurface flow. Thus, this model typically makes no differentiation between surface and groundwater return flow, except where necessary. To govern return flows from ditches, a central converter was created that takes into consideration the many different factors that affect return flow including, but not limited to, the degree of soil saturation, temperature, time of year, recent precipitation events, and evapotranspiration et al. This central converter governs the return flow on some of the ditches by relegating a portion of the ditch’s flow back to the river. For this portion of the overall model, Phase I of III, this percentage is flat and set to 25% of the ditch flow. While the percentage is flat, the amount of water returning to the river or other ditches is a direct reflection of flow in the diversion. Thus, the central converter indirectly takes the above mentioned factors into consideration. It is presumed that Phase II and III of the overall study will elaborate on this function when the interface is added to the existing infrastructure that would allow for changes in irrigation practices to be directly input into the model.

Where different return flow regimes are known or suspected to exist, such as where a diversion transports water completely away from the river, or where there is a channel that actually brings water back to the river, the central converter is not used. Rather, in these cases, an individual return flow converter is used to regulate return flow of the ditch in question.

The above mentioned return flows exist primarily on a monthly time scale. There is also an aspect to groundwater return flows that operate on a larger, annual time scale. For example, when drought conditions persist for one year, then another year, and so on, the water table gets successively lower each and every year. Along the same lines, when successive years of heavy precipitation occur, the water table rises with each additional wet year. To reflect this behavior, another central converter takes a portion of every ditch's water and directs its flow into an underground aquifer reservoir. Flow out of this aquifer back to the surface is regulated such that successive years of drought will minimize aquifer outflow and successive wet years will increase aquifer outflow. Ascertaining where to partition this flow was done by running the 1990-1999 simulation and determining what area of the river was in need of surplus water that otherwise could not be accounted for from surface water or monthly groundwater returns. One particular location was found most lacking: prior to Gage 10311400 on the Main Carson River at Deer Run. This gage is located just east of Carson City, where the river changes directions from north to east toward Dayton Valley (Figure 20).

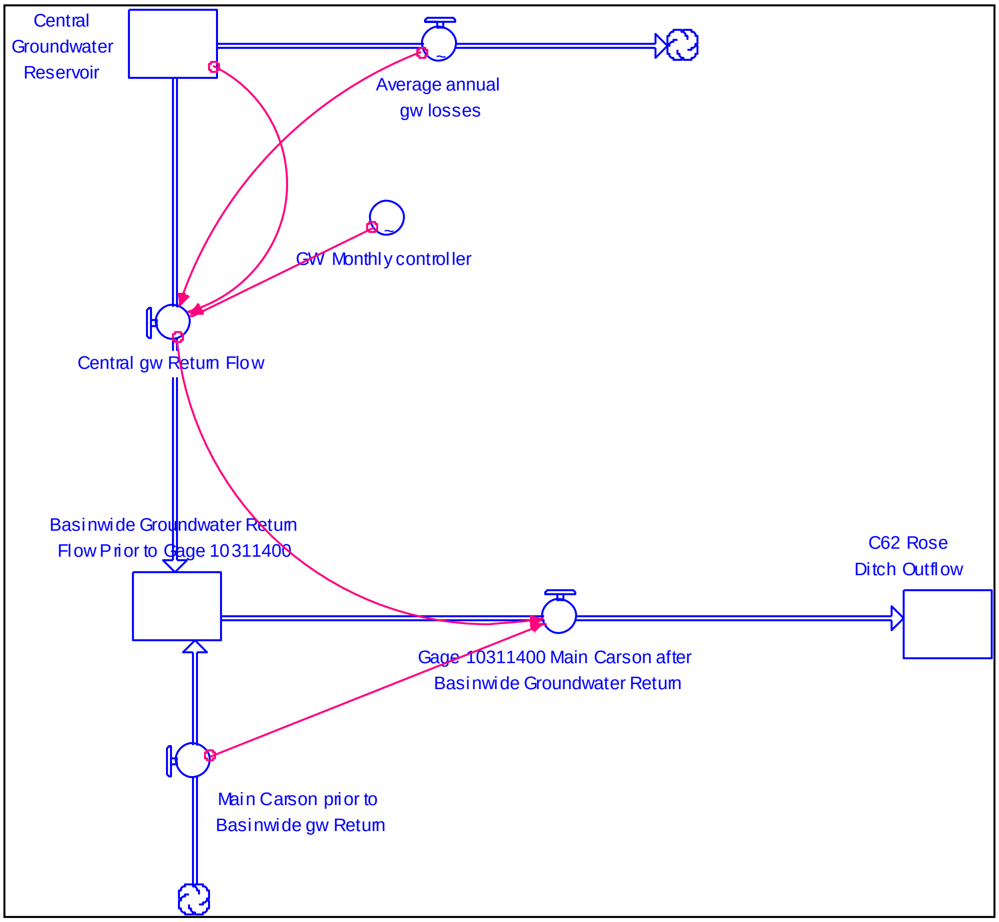


Figure 20. Central Groundwater Reservoir

Thus, varying amounts of flow from the aquifer seep into the river just prior to Gage 10311400. Realistically, such river seepage occurs over a large area. For modeling purposes, however, having aquifer discharge confined to one central location serves the purpose of the model. The amount of flow is based on the last few years of headwater flow, which is controlled by annual precipitation in the model.

Thus for most ditches, a portion of water is consumed by crops, a portion is lost to evaporation, a portion returns to the river, and a portion recharges the aquifer (Figure 21).

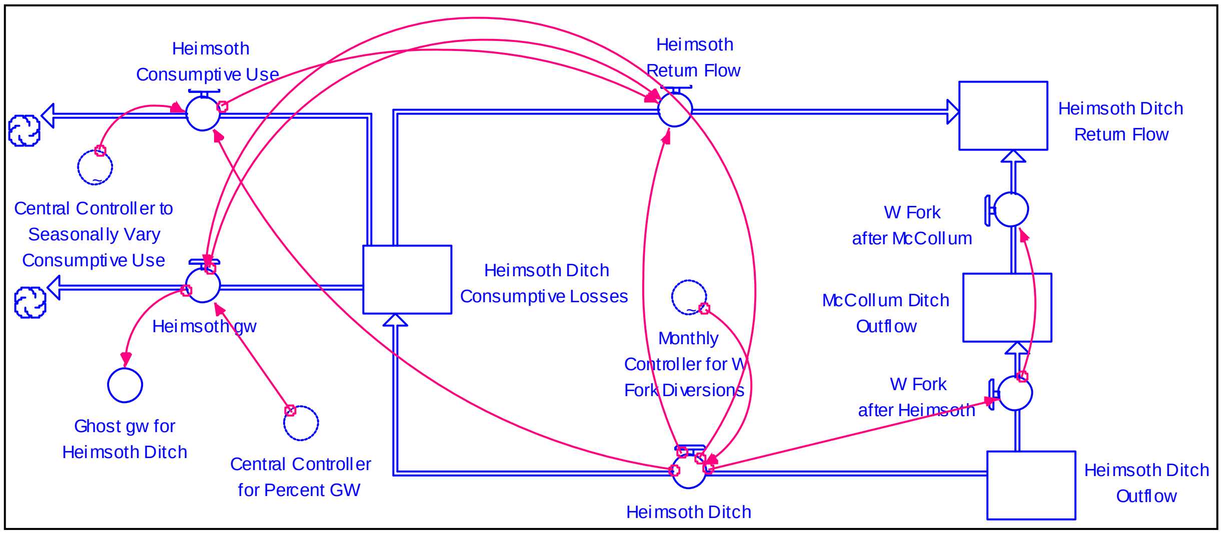


Figure 21. Heimsoth Diversion

For those ditches with no direct return flows, that unused water is assumed to have been transported far enough away from the system so that its influence is not observable and thus, not reflected in the model (Figure 22).

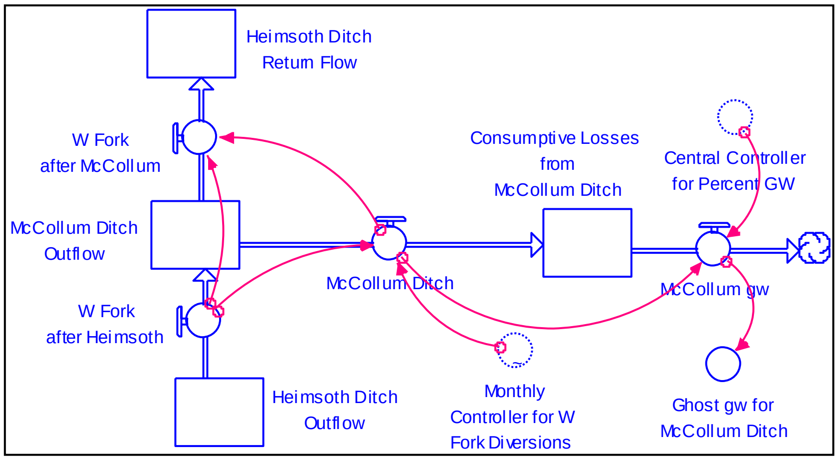


Figure 22. McCollum Diversion

2.2 Model and Data Preparation

The model was built in sections. Conceptual data was used to develop empirical relationships for surface flows (stream flows, diversions). Discrepancies in flows were soon discovered, and groundwater interactions and return flows were used to simulate these discrepancies as a functioning part of the system.

Much of the model relies on USGS data. Every USGS gage used in this report had average monthly flows in cfs available directly through USGS websites. Alternatively, gaged data from the Federal Water Master was received in acre-feet/month so formatting to average monthly cfs was necessary.

After the data was formatted, attempts were made to find relationships within data sets, such as relationships that existed between diversions and the closest gage on the river. This in turn was followed by building data sets of estimated flow at specific portions of the river via adding and subtracting inflows and outflows that occurred between the two points as was discussed above. This was done to enable future scenario running possible. For example, if agriculture was taken out of production, the specific ditch that supplied water for the agriculture in question would carry less water, or possibly none at all. This decrease in ditch flow would in turn result in more flow in the river for the downstream user, and less flow for a user who relied on return flows from that ditch.

The process of building the above data sets occasionally involved estimating data where the period of records did not exist for the model calibration period. To solve the problem of non-overlapping data sets, existing data was correlated to another data set, typically the next closest previous gage or a headwater gage, and based on the data's relationship with that gage, the missing data was estimated. Then this estimated data, in conjunction with the limited data of record, was used to identify a trend line.

In situations where the historical years of record did overlap and the data still did not correlate, it was typically due to an incorrect assumption, a change in practice (diversion point moved), or in rare cases, faulty data. However, some of the diversion data simply did not correlate with adjacent river flow. This was often the case in many of the diversions near Dayton for the months of April and May. In these cases, it appears that other factors, notably the weather, play a larger role in predicting diversion flow than adjacent Carson River flow. Precipitation falls far more frequently in April and May versus the rest of the summer. If, for example, April was a wet month, there would be less need to irrigate. Thus the situation could arise where despite high runoff flows in the river, the ditch runs relatively dry. In these cases, mean flow was used where the R^2

value was low and the trend line, if any, was not representative of any known or posited relationship.

The following chapter and subsequent chapters that focus on the East Fork (Chapter 7) and the Main Carson River after the East and West Fork Confluence (Chapter 8) will describe the Upper Carson River Watershed Model. Each section provides descriptions of the data sets used, summary statistics of that data (mean, range, standard deviation), methodology used to derive the relevant flow relationships (mean or linear/non-linear regression), R^2 ranges of regression analysis equations used to define flow, and as appropriate, unique characteristics of the particular diversion, tributary, or portion of the river. Tables of the historic records for each gage are located in the appendices (West Fork: Appendix A, East Fork: Appendix B, Main Carson: Appendix C).

2.3 Development of the Mathematical Model of the Carson River

2.3.1 Data Used in Modeling the Carson River

The U.S. Geological Survey (USGS) and the Federal Water Master's Office are the principal agencies that collect surface water data in the Upper Carson River Basin. For the model this report describes, 18 USGS gaging stations data sets (Table 3) and 23 Federal Water Master derived diversion data sets (Table 4) were used.

There are other USGS and Federal Water Master derived data sets for various surface waters in the Upper Carson River Basin, however, for one or more of the following reasons they were not used to build the model: 1) too limited a data set, 2) diversion no longer in use, 3) point of diversion change, 4) inaccurate data, 5) irrelevancy to project, and 6) insignificant flow.

The USGS data sets were derived from automatic recorders that record continuous flow. This data is then published on the USGS website in varying formats including real-time, daily, monthly, annual, and peak flows. For this project, monthly data was used.

Table 3. USGS Gage Records Used

Gage Number	Location	Type of Flow	Period of Record
10308200	E. Fork Headwaters N of Markleeville, CA	River	1960-current
10308800	Bryant Creek SE of Dresslerville, NV	E. Fork Tributary	1961-69, 1978-79, 1995-current
10309000	E. Fork between the Stateline and Dresslerville, NV	River	1890-93, 1901-05, 1908-10, 1925-27, 1940-current
10309035	Indian Creek SE of Dresslerville, NV	E. Fork Tributary	1994-1998
10309050	Pine Nut Creek SE of Gardnerville, NV	E. Fork Tributary	1980-1997
10309070	Buckeye Creek E of Minden, NV	E. Fork Tributary	1980-1997
10309100	E. Fork Carson at Minden, NV	River	1974-1984, 1994-98
10310000	W. Fork Headwaters at Woodfords, CA	River	1901-1907, 1939-current
10310300	Fredricksburg Canyon Creek near Fredricksburg, CA	W. Fork Tributary	1989-2001
10310402	E. Branch Brockliss Slough at Muller Lane W. of Minden, NV	River	1994-1998
10310403	W. Branch Brockliss Slough at Muller Lane W. of Minden, NV	River	1994-1999
10310448	Ambrosetti Pond Outlet near Genoa, NV	Carson River Tributary	1993-1997, 1999-current
10310500	Clear Creek S of Carson City, NV	Carson River Tributary	1948-1962, 1989-current
10311000	Carson River S of Carson City, NV	River	1940-current
10311300	Eagle Valley Creek at Carson City, NV	Carson River Tributary	1985-current
10311400	Carson River at Deer Run Road E of Carson City, NV	River	1979-1985, 1991-current
10311700	Carson River at Dayton, NV	River	1994-1997, 2002-current
10312000	Carson River W of Fort Churchill, NV	River	1911-current

Table 4. Federal Water Master Gage Records Used

Gage Number	Location	Type of Flow	Period of Record
C61 Mexican Ditch	Carson River SE of Carson City, NV	Carson River Diversion	1989-current
C62 Dayton Ditch	Carson River SW of Dayton, NV	Carson River Diversion	1984-current
C64 Fish Ditch	Carson River S of Dayton, NV	Carson River Diversion	1984-current
C65 Baroni Ditch	Carson River N of Dayton, NV	Carson River Diversion	1984-current
C66 Cardelli Ditch	Carson River N of Dayton, NV	Carson River Diversion	1984-current
C67 Quilici Ditch	Carson River N of Dayton, NV	Carson River Diversion	1984-current
C68 Gee Ditch	Carson River NE of Dayton, NV	Carson River Diversion	1985-current
C69 Koch Ditch	Carson River NE of Dayton, NV	Carson River Diversion	1985, 1991-current
C70A Houghman and Howard Ditch	Carson River W of Fort Churchill, NV	Carson River Diversion	1985, 1987-current
C71 Upper Buckland Ditch	Carson River W of Fort Churchill, NV	Carson River Diversion	1984-current
C72 Lower Buckland Ditch	Carson River At Fort Churchill, NV	Carson River Diversion	1984-2002
C76 Snowshoe Thompson #1	W. Fork SW of Woodfords	W. Fork Diversion	1984-1996, 1998-current
C76 Snowshoe Thompson #2	W. Fork SW of Woodfords	W. Fork Diversion	1996-2004
C78 Fredricksburg Ditch	W. Fork near Paynesville, Ca	W. Fork Diversion	1984-2004
C80 Brockliss Slough	W. Fork at Ruhenstroth Dam SW of Gardnerville, NV	River	1984-1986, 1988-current
C81 Brockliss Slough	Brockliss Slough at Scossa Box W of Gardnerville, NV	River	1984-current
C82 Allerman Canal	E. Fork E of Dresslerville, NV	E. Fork Diversion	1984-current
C83 Virginia Ditch	E. Fork N of Dresslerville, NV	E. Fork Diversion	1984-current
C84 Rocky Slough	E. Fork N of Dresslerville, NV	E. Fork Diversion	1984-current
C85 Edna Ditch	E. Fork N of Dresslerville, NV	E. Fork Diversion	1984-current
C87 Cottonwood Slough	E. Fork SE of Gardnerville, NV	E. Fork Diversion	1984-current
C88 Henningson Ditch	E. Fork SE of Gardnerville, NV	E. Fork Diversion	1984-current
C89 Heyburn Ditch	E. Fork N of Minden, NV	Diversion Return Flow	1984-1985, 1987-current

Federal Water Master data sets were derived in two ways. More commonly, there is a record with continuous data, or an average daily value for every day during the irrigation season. At those particular stations, flow is measured by an automatic recorder that tracks the water levels in the ditch over time. Then, using a rating table based on a series of historical and continuously updated measurements taken at different water levels, the water stage is translated to a rate of flow. For stations such as the Ruhenstroth, Scossa and Dressler gages, the calibration measurements are typically done with a weir rule over the boards in the diversion dam, or when possible, done by current meter. And for other stations, records are based on intermittent data. These stations do not have a continuous level recorder, rather the measured values are taken when the Water Master's field person actually visits the station. The intermittent values are then used to calculate an average value for the month and that average is multiplied by the number of days in the month to come up with a total amount of water in acre-feet diverted for that month (D. Wathen, personal communication, 2005).

Discussion of the predictive flow equations that govern the first major diversion in the West Fork, Snowshoe Thompson Ditch #1, are far more in depth so as to provide the reader with context and insight into the methodology used throughout the model. Subsequent diversion and tributary discussions are far more limited.

The years 1990 to 1999 were chosen as the test simulation to assist in developing the model. This specific data set was chosen for a number of reasons. One, this particular set of years is simplistic in that it represents one decade. Two, most of the diversions have data from 1984-2004, so this is the one decade that can best compared to actual data. Three, this particular decade provides significant variance between years and is quite representative of the way drought years and wet years run in cycles. The years 1990 to 1992 are drought years. 1993 is the classic “drought buster” year, however, when followed by another year of drought in 1994, 1993’s “drought busting” status is shown to be somewhat limited. The years 1995 through 1999 provide examples of wet years. 1997 provides a one hundred year flood event in January.

2.3.2 Modeling the West Fork of the Carson River.

The West Fork headwaters originate high in the Sierras at an approximate elevation of 8,600 feet (Horton, 1997b). For modeling purposes, the West Fork begins nearly 3,000 feet lower at Gage 10310000, elevation 5,750 feet, in Woodfords, CA.

West Fork Headwaters (USGS Gage 10310000)

Gage 10310000 is the model's beginning of the West Fork and thus it is this gage's relationship with other diversions that will control the flow of the first few diversions and tributaries until the next river gage is reached. In the model, flow at this gage is linked to precipitation. Thus, it is the hydrologic condition that governs the model's headwater flows. Gage 10310000 has a long period of record: 1901-1906 and 1937-current (2004). Based on this period of record, the mean annual flow of this stretch of the West Fork is 78,265 acre-feet with a standard deviation of 35,540 acre-feet. As evidenced by the large standard deviation, considerable flow variation is commonly observed at this site. The maximum total annual flow recorded at this gage is 185,682 acre-feet (1983). The minimum total annual flow recorded at this gage is 18,904 acre-feet (1977). Figure 23 provides a graphical representation of this ditch's mean and extreme annual flows in cfs.

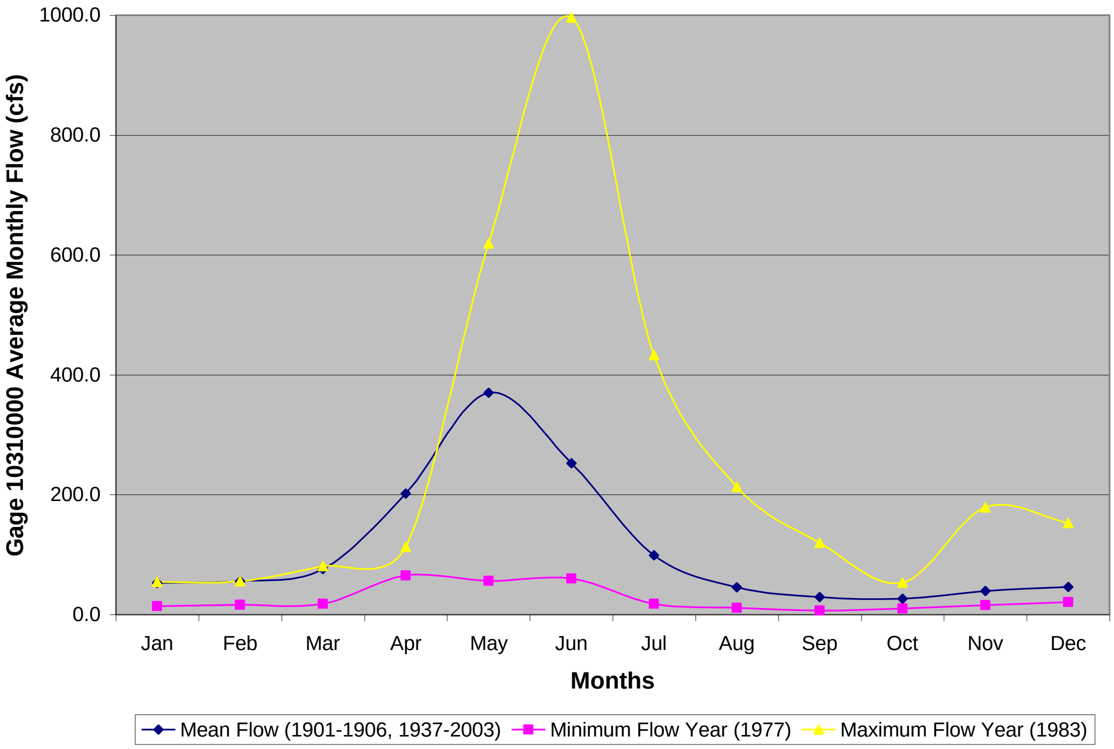


Figure 23. Mean, Minimum, and Maximum Annual Flows for West Fork Headwaters (Gage 10310000)

C76A Snowshoe Thompson Ditch #1

The first major diversion encountered in the West Fork is Snowshoe Thompson Ditch #1. Snowshoe Thompson #1 is a Federal Water Master gaged diversion with a typical Federal Water Master period of record of 1984-2004, with exception to 1997 when no data was recorded. Based on this record, the mean annual flow of this ditch is 3,924 acre-feet with a standard deviation of 433 acre-feet. The maximum total annual flow recorded at this gage is 4,606 acre-feet (2000). The minimum total annual flow recorded at this gage is 3,351 acre-feet (1987). Figure 24 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

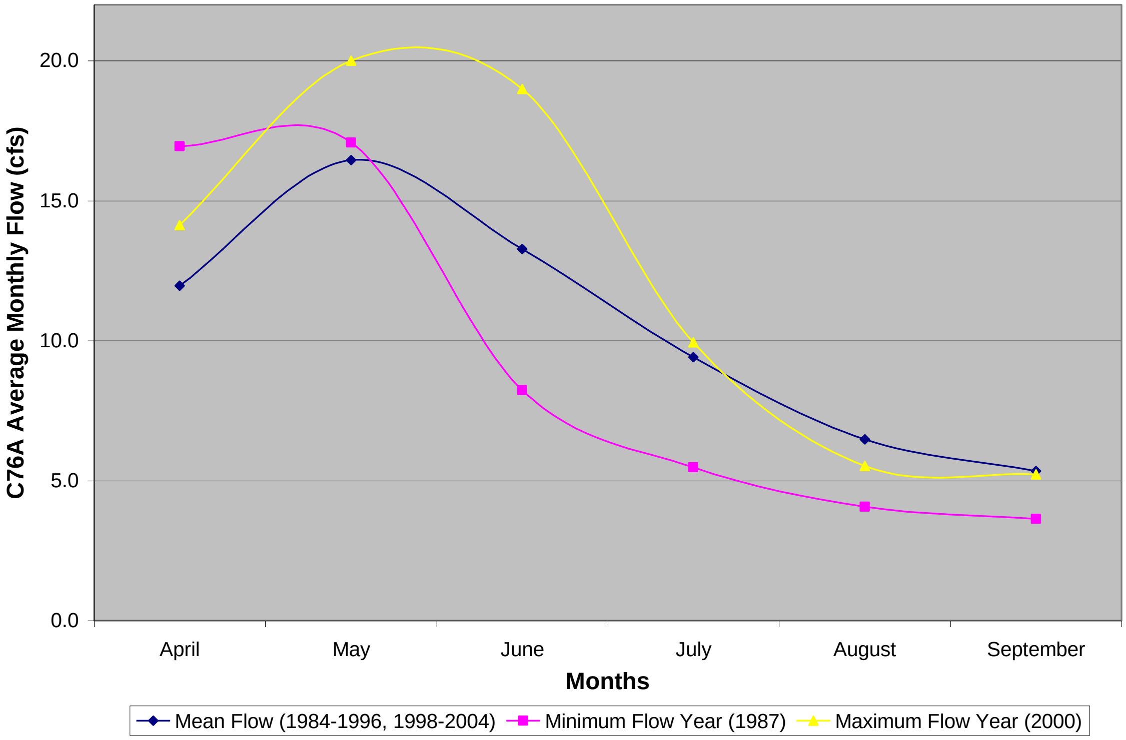


Figure 24. Mean, Minimum, and Maximum Annual Flows for C76A Snowshoe Thompson Ditch #1

Records at this ditch were kept from March through October, like most of the other upstream ditches. The downstream gages in Dayton Valley, however, typically only have records from April through September. This is apparently due to differences in monitoring between the water masters that control these different sections of the river (D. Wathen, personal communication, 2005). From a governance point of view, irrigation diversions are only supposed to occur from March 15th through October 15th. Typically, the irrigation season does not get started until late March or April (D. Wathen, personal communication, 2005), so this disparity is somewhat of a moot point for March at least. Irrigation diversions are more common in October, however, so where records were kept (upstream gages), attempts were made to model flow for that month. Flow in the Dayton Valley ditches often run dry in September, so defining October flow as zero is a reasonable assumption.

Another systemic problem exists in that for both March and April, diversion records are often left blank. Conversations with the Federal Water Master about this issue revealed that data gathering for these months is as sporadic as the flow. Thus, the question arises, should these flows be counted as 0 cfs when using regression and/or calculating the mean? Finding a solution to this issue is compounded by the fact that occasionally 0.0 flow values are given for these months, so this would seem to suggest that a non-recorded month is not necessarily indicative of 0 cfs. To maintain consistency, blank records were presumed to be just that: a non-record. Only records which contained a numerical value, such as 0.0, were included in regression or mean calculation.

The records for both March and October for this ditch were sporadic. For March, records were kept for four of the twenty years of record. For October, records were kept for seven years, with an average flow of less than 2 cfs and there was no pattern to the record keeping. For these reasons, ditch flow in March and April were presumed to be 0.

Regression analysis was used to find equation that could predict flow in Snowshoe Thompson Ditch based on flow at the West Fork headwater gage. In the graphs that follow, the dependent variable (Snowshoe Thompson Ditch) is correlated to the independent variable (Gage 10310000 West Fork Headwaters) and a trend line is shown. The equation of the trend line as well as the R^2 value are given in the upper right hand corner of the graph. Below is the graph for April.

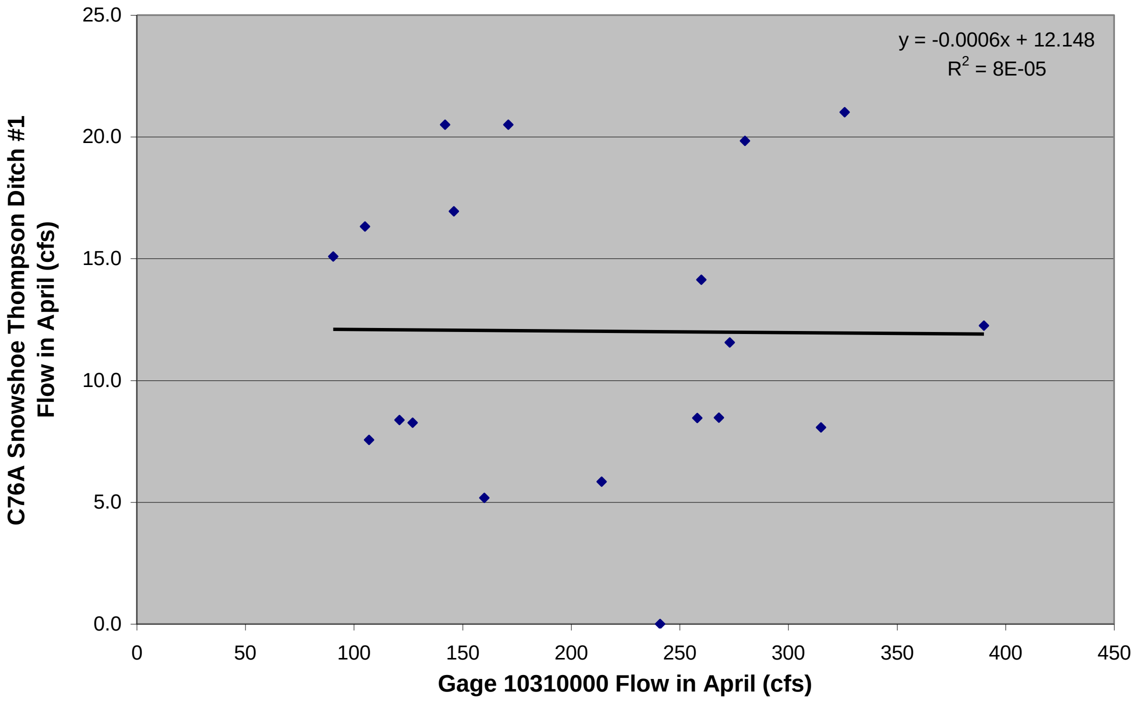


Figure 25. April Flow Derivation for C76A Snowshoe Thompson Ditch #1

As can be seen from Figure 25, linear regression analysis failed to reveal a correlation between the two gages. Similarly, non-liner regression (natural log) also failed to reveal a relationship. As was explained above, when the R^2 is close to 0, the implication is that all of the variation can be explained by the mean. Here then, given the low R^2 value, the trend line is of no use and the mean is used to represent flow in Snowshoe Thompson Ditch #1 for April. In May, as flow in the river increased, it appears from Figure 26 that flow in Snowshoe Thompson Ditch #1 decreases.

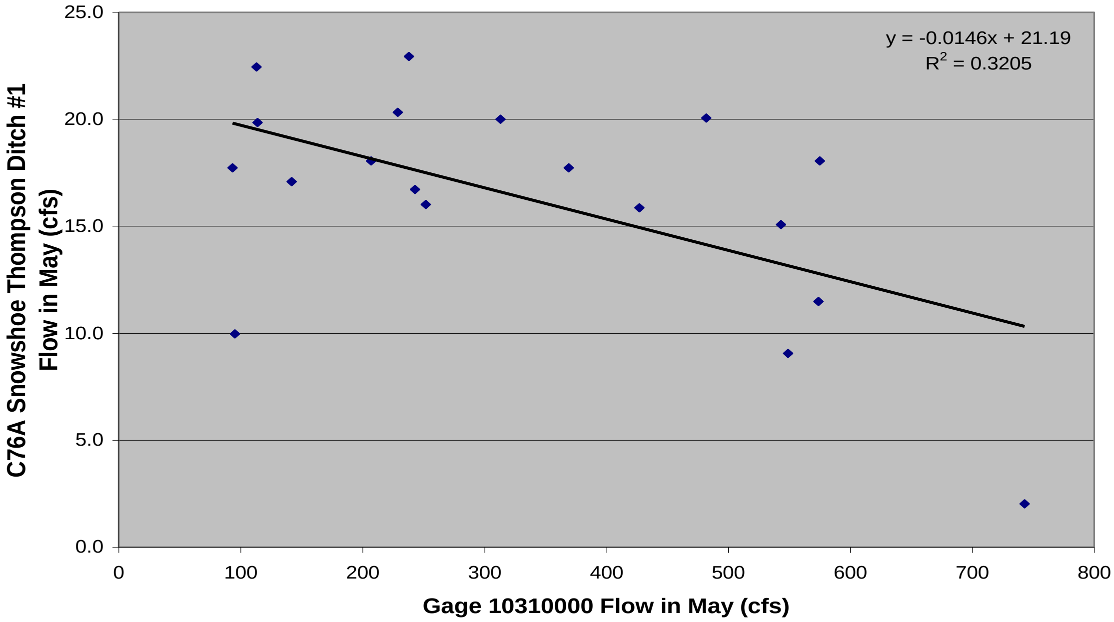


Figure 26. May Flow Derivation for C76A Snowshoe Thompson Ditch #1

However, this sort of relationship is not as strong when an outlying point on the bottom right hand corner of the graph, (723, 2) is removed, as is seen in Figure 26.

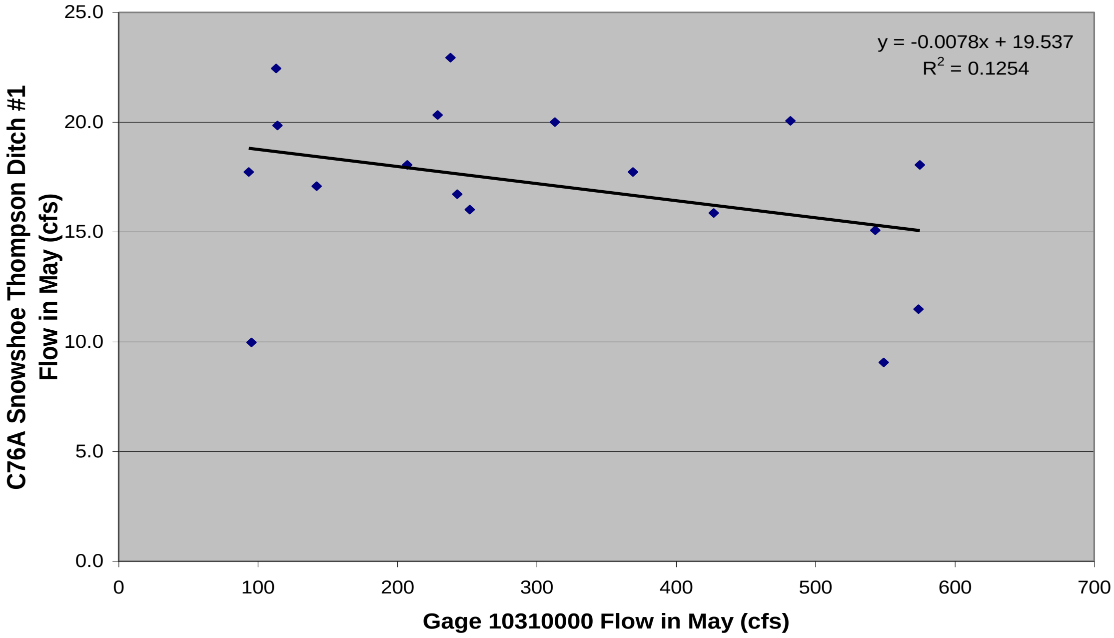


Figure 27. New May Flow Derivation for C76A Snowshoe Thompson Ditch #1

As the two graphs show, one data point can exert a very strong influence over the trend. In cases like this, where the data and/or relationship is in question, the outlier is removed and the trend line examined. Here, while the trend line may explain 12.5% of the variation, there is simply too much scatter to warrant the use of any trend line. Thus the mean is used for May as well. Graphs for June through September are shown in Figures 28-31. As is common in most of the diversions, these months correlate well to adjacent flow in the river with a natural log trend line.

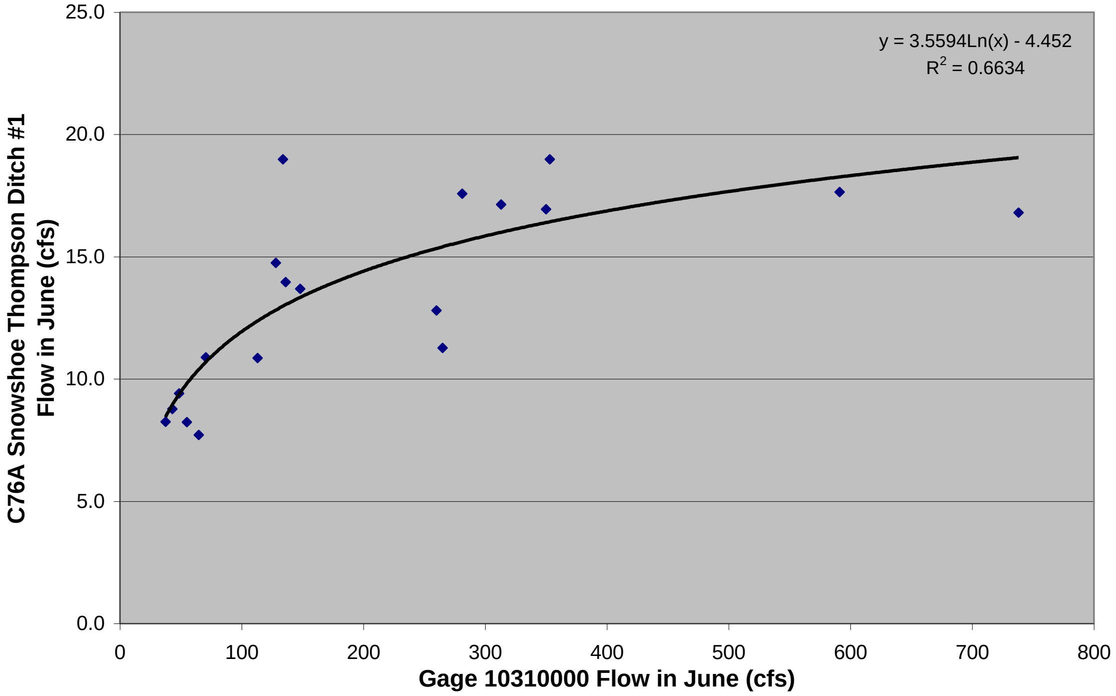


Figure 28. June Flow Derivation for Snowshoe Thompson Ditch #1 (C76)

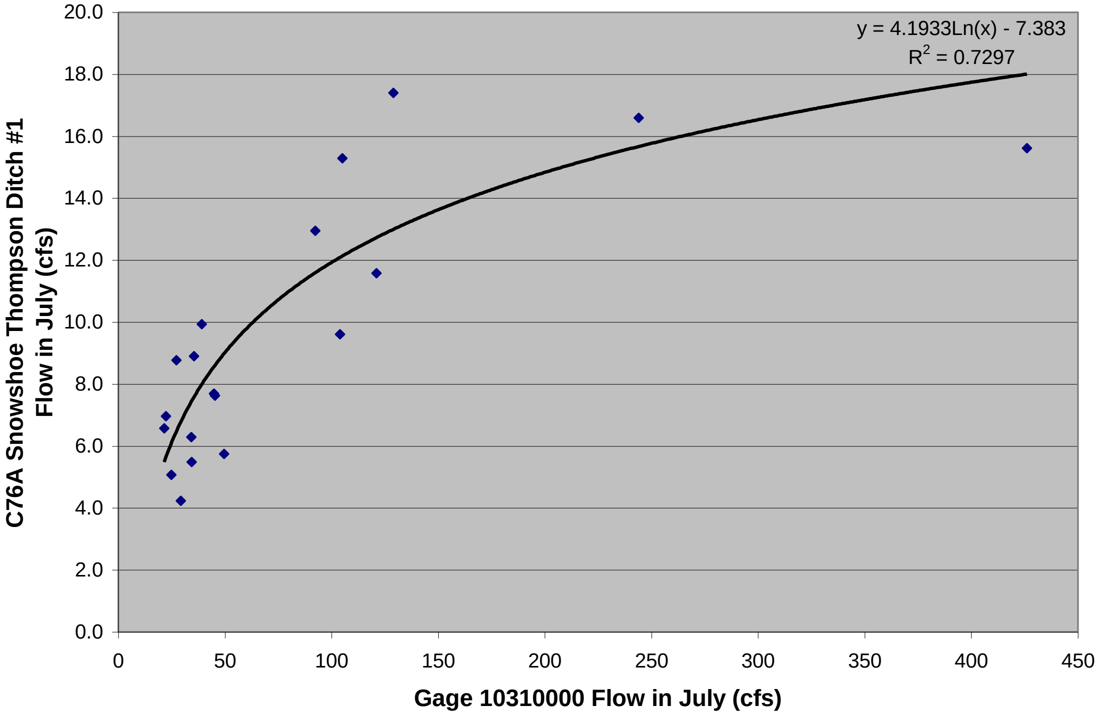


Figure 29. July Flow Derivation for C76A Snowshoe Thompson Ditch #1

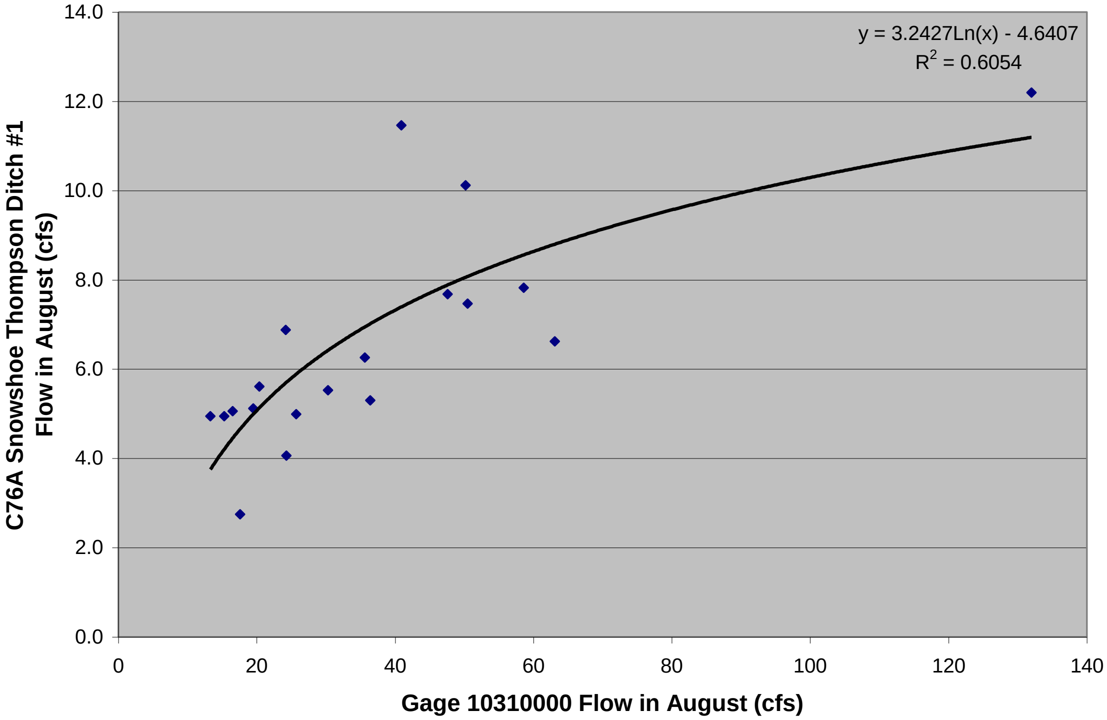


Figure 30. August Flow Derivation for C76A Snowshoe Thompson Ditch #1

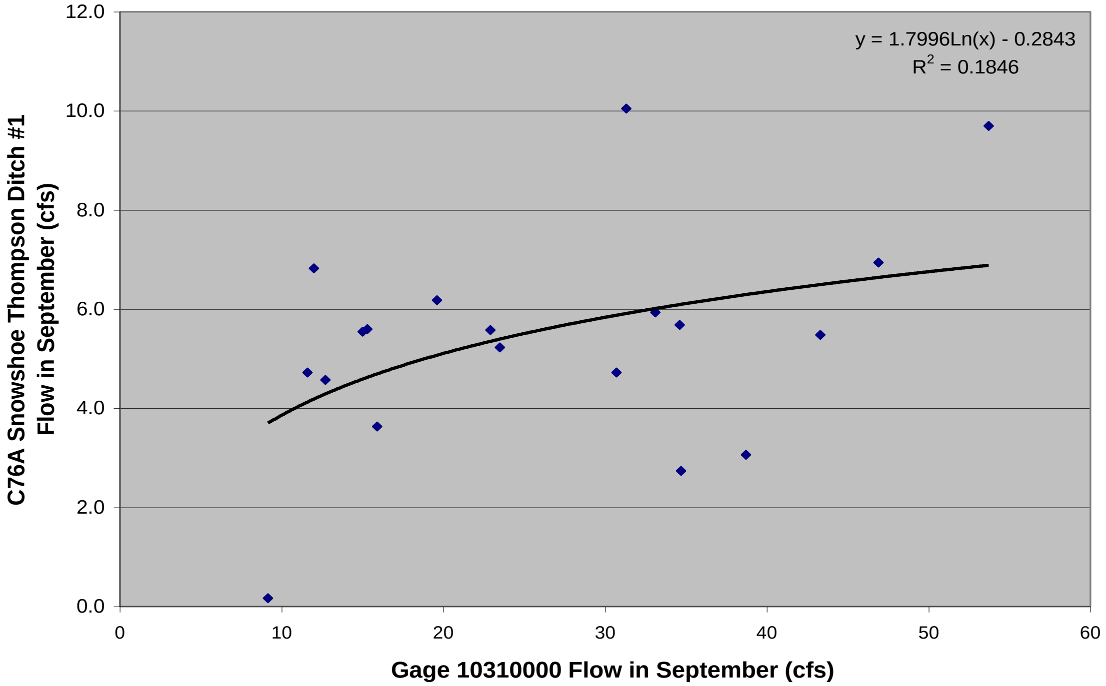


Figure 31. September Flow Derivation for C76A Snowshoe Thompson Ditch #1

While September's trend line explains only 18.5% of the variation, the trend exhibited is in sync with the other months and intuitively, the trend makes sense. Thus, it is used for the model. Table 5 shows the numerical values for the natural log and constant converters in the model that govern C76 Snowshoe Thompson Ditch #1's flow. Average Flow is placed alongside the converter's values to provide context.

Table 5. C76A Snowshoe Thompson Ditch #1 Converter Values

Month	ln coef	Constant	avg. flow (cfs)
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	0	12	12
May	0	16.4	16.4
Jun	3.56	-4.5	13.3
Jul	4.19	-7.4	9.4
Aug	3.24	-4.64	6.5
Sep	1.8	-0.28	5.3
Oct	0	0	0
Nov	0	0	0
Dec	0	0	0

The flow equation for Snow Thompson Ditch #1 is:

(ln coef for C76 #1*LOGN(Gage 10310000))+Constant for C76 #1

Thus, when the model is run for one year, the *ln coef* converter and the *constant* converter would create flow in the ditch based on adjacent flow in the river in accordance with the trend lines above. For the ten year simulation run of 1990-1999, the above twelve point data sets were repeated ten times so that each converter has one hundred and twenty data points as opposed to twelve. Simulation of the predicted diversion using the above equation and data reported by the water master is shown in Figure 32.

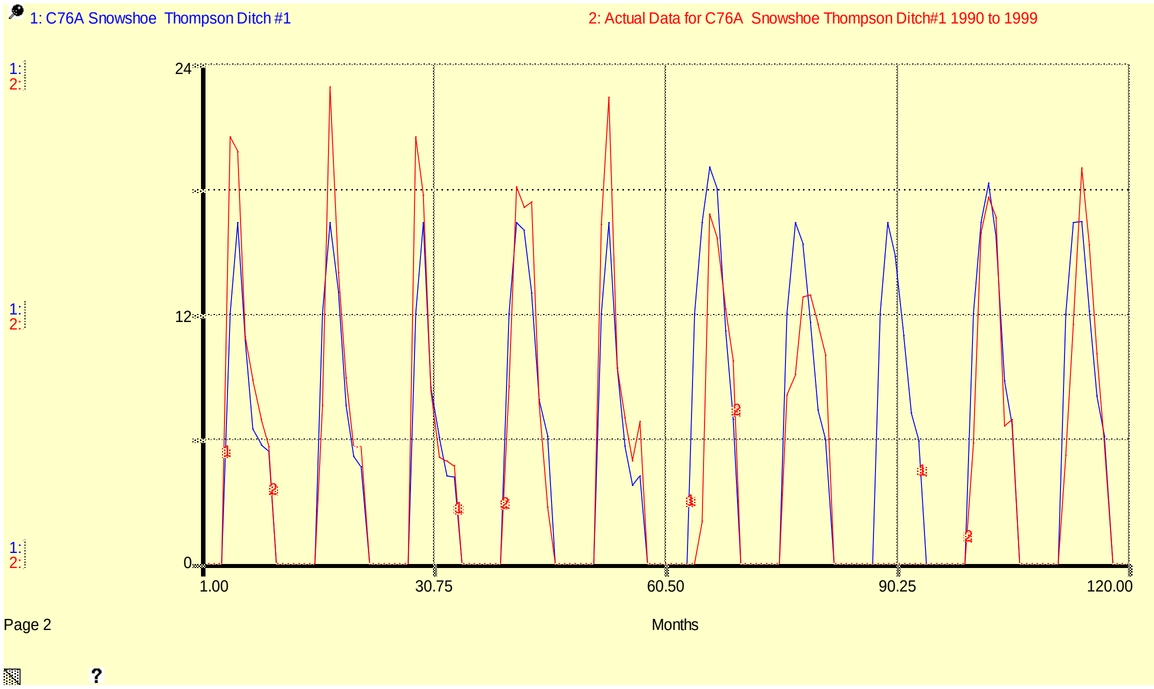


Figure 32. C76A Snowshoe Thompson Ditch #1 1990-1999 Simulation, Actual vs. Model

The model somewhat under predicts the higher diversions and somewhat over predicts the lower diversions. Overall, however, the model results are fairly accurate. Given the human element involved in the governing of the Carson River, results such as above are deemed a success. The actual data for the 1997 irrigation season (points 88-93 on graph) is not shown on the graph because that year's data is not available.

This section purposefully went into far more detail than subsequent diversion ditches. Henceforth, individual sections will provide a more generic description of the diversion or tributary in question, and will only go into details in matters concerning unique characteristics or issues of the particular reach being discussed.

C76B Snowshoe Thompson Ditch #2

The next major diversion encountered in the West Fork is Snowshoe Thompson Ditch #2. Snowshoe Thompson #2 is a Federal Water Master gaged diversion with a period of record of 1996-2004. Based on this record, the mean annual flow of this ditch is 2,211 acre-feet with a standard deviation of 1,028 acre-feet. The maximum total annual flow recorded at this gage is 4,326 acre-feet (1997). The minimum total annual flow recorded at this gage is 1,424 acre-feet (2001). Year to year variation is the norm for this gage. Figure 33 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

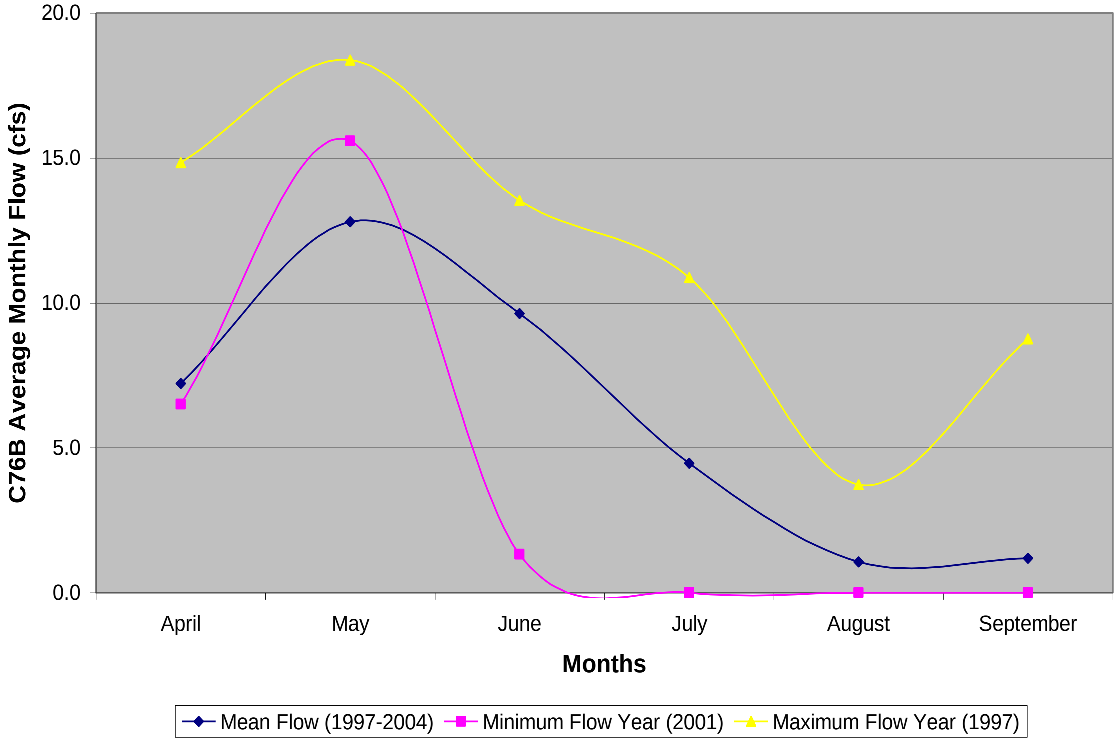


Figure 33. Mean, Minimum, and Maximum Annual Flows for C76B Snowshoe Thompson Ditch #2

Records at this ditch were kept from April through September, with the exception of 1997, when a record for March (1.5 cfs) was kept. Flow in the ditch was correlated to West Fork headwater flow minus the flow of Snowshoe Thompson Ditch #1. Regression analysis revealed well correlated natural log trend lines for April and June through September, with R^2 values ranging from a low of 0.46 in April to a high of 0.84 for July. There was no observable trend in May so that month is defined by its mean. Results of the 1990-1999 simulation appear below. Historical data for this ditch is only available for 1996-1999.

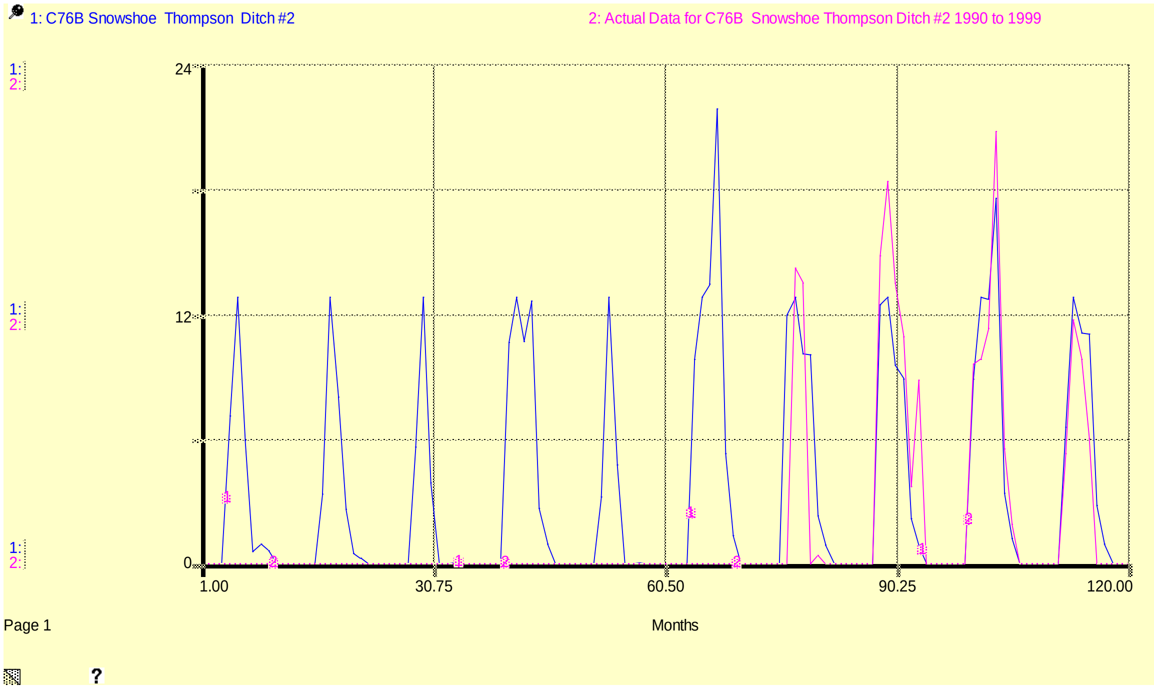


Figure 34. C76B Snowshoe Thompson Ditch #2 1990-1999 Simulation, Actual vs. Model

Of particular mention is the model's under prediction of 1996, 1997, and 1998. This is due to the fact that the data set consists of nine years, only eight of which were used in the model (no 2004 data available as of this writing for Gage 10310000). Here, we are looking at four rather wet years. The other years in the data set, 2000-2003, were drought years. Thus, if those years were modeled, presumably the model would somewhat over predict those years. This is because the trend line essentially represents the middle of these two spheres of influence.

Major Ungaged Ditches on the West Fork Prior to the Brockliss Slough

This section describes the methodology behind the creation of the flow parameters of the major ungaged diversions prior to the Brockliss Slough as well as the actual flow equations that govern these diversions. It is estimated that these ditches run at an average of ¾ their capacity prior to the river going on regulation (D. Callahan, personal communication, 2005). Typically, this portion of the river goes on regulation some time in June. When the river goes on regulation, these ditches operate on a weekly on/off basis. That is, the ditches carry at or near their capacity for one week and then run dry (or quite low) for a week. This rotation repeats itself until the ditches are dropped due to low priority and/or lack of flow. Table 6 lists these ditches and their estimated average flows, beginning with the most upstream diversion and ending with the last major ungaged diversion prior to West Fork's full diversion to the Brockliss Slough.

Table 6. Estimated Average Flows of Major West Fork Ungaged Diversions

Ditch Name	Estimated Average Flow (cfs) prior to the River Going on Regulation
Heimsoth Ditch	20
McCollum Ditch	15
Deluchi Ditch #1	15
Deluchi Ditch #2	15
Falke Tilman Ditch	30
Thran Ditch	15
Whyatt Ditch	12
Company Ditch	20
Dressler Ditch	12
Jones East Ditch	15

The system of rotation described above is practiced throughout the Upper Carson River Basin. Thus, to understand what sort of flow regime this practice of regulation would manifest, one need only look to many of the gaged diversion to identify a common pattern of flow. The archetype is little, if any, flow in March, followed by a peak in May, followed by a gradual decrease throughout the summer, and ending with little, if any, flow in October. In drought years, the end of irrigation arrives sooner (September, even August). In wet years, the peak typically occurs later (May-June).

The 1990-1999 simulation was used to determine which month is the most appropriate month to peak diversion flow. A known gaged diversion, C80 Brockliss Slough at Ruhenstroth Dam, was used to test the differences between a May and June peak diversion for the diversions prior to it. Originally, it was thought that the peak should be completely controlled by flow in the Carson so that a late runoff would cause the peak to occur in June rather than May. However, when river flow was solely responsible for dictating the timing of peak flows, the model was consistently over estimating May flow in the Brockliss Slough at Ruhenstroth Dam. Thus, it appeared that May was decidedly the month when diversion flows do, in reality, peak, with exception to the years where an unusually late runoff occurs.

A combination of IF THEN ELSE logic and categorizing the diversion as a fraction of adjacent river flow was used to create flow regimes for the diversions listed above. IF THEN ELSE logic was used primarily to create the peak flow in May as well as create an upper limit to the diversion throughout the summer in accordance with the ditch's estimated capacity. It was also desired to link flow in the ditch to flow in the river to reflect how ditch flow is related to the winter snowpack and subsequent runoff. This was done by identifying ditch flow as a fraction of the river's flow. This, in conjunction with the established upper limit, allowed for the diversion flow to reflect conditions in the river, and thus mimic being dropped due to priority and/or low flow. An example of the governing logic is shown below.

```
IF
(Monthly__Converter_for_W__Fork_Diversions>1)
THEN IF
(.05*W_Fork__after_Snowshoe*Monthly__Converter_for_W__Fork_Div
ersions<15)
```

```
THEN
(.05*W_Fork__after_Snowshoe*Monthly__Converter_for_W__Fork_Diversions)
ELSE 15
ELSE IF
(.05*W_Fork__after_Snowshoe*Monthly__Converter_for_W__Fork_Diversions<10)
THEN
(.05*W_Fork__after_Snowshoe*Monthly__Converter_for_W__Fork_Diversions)
ELSE 10
```

For the non-computer programming readers, the above code is not as complicated as it may appear to be at first blush. Here, the *Monthly Converter for West Fork Diversions* is used to create the situation where May is the typical peak flow month. In May, the *Monthly Converter for West Fork Diversions* is greater than 1 and in all other months, it is less than one. The IF THEN ELSE logic sets the upper limit to 15 cfs for May and 10 for other months. The flow, *W Fork after Snowshoe*, is the West Fork Carson River's flow adjacent to the diversion. All other ungaged diversions along this reach are governed by similar logic, with the upper limit set to reflect estimations of the ditch's capacity. As with other diversions, these ungaged diversions also have consumptive losses, flow to the aquifer, and return flow. A representative graph of these ungaged diversions and related flow is shown in Figure 35.

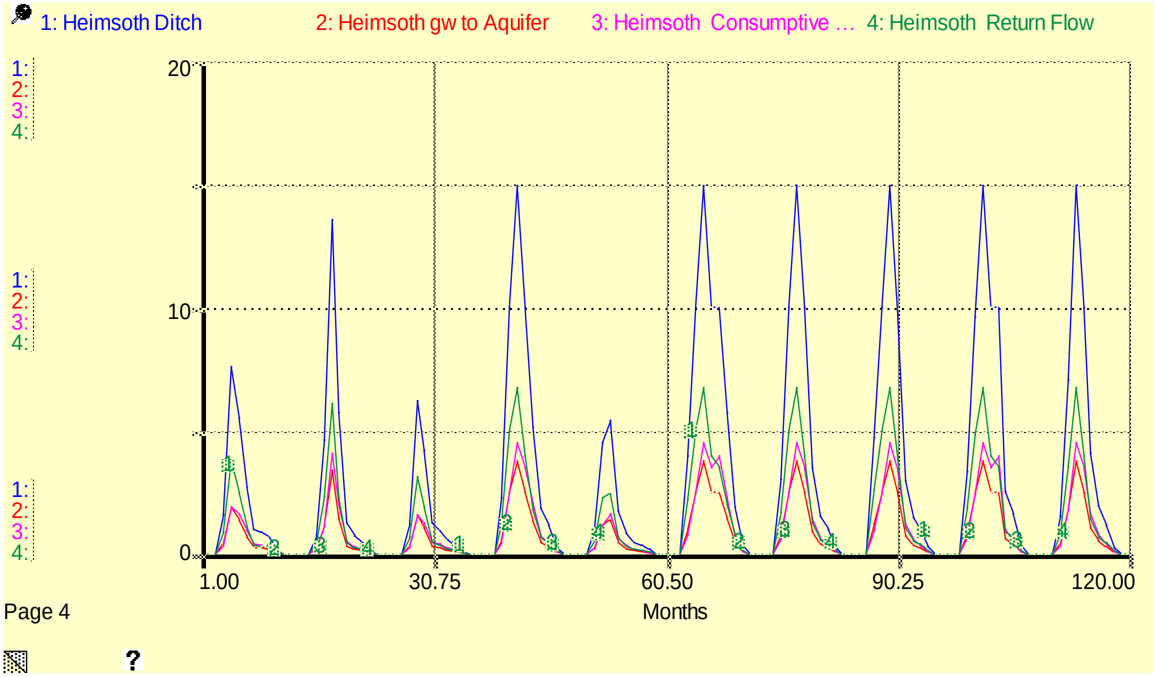


Figure 35. Inflows and Outflows of Heimsoth Ditch, 1990-1999 Simulation

C78 Fredricksburg Ditch

After supplying the Heimsoth Ditch and McCollum Ditch (discussed above), the West Fork next feeds the Fredricksburg Ditch, which carries water to the north-northwest and in the process feeds a number of ungaged ditches. Fredricksburg Ditch is a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 7,565 acre-feet with a standard deviation of 1,762 acre-feet. The maximum total annual flow recorded at this gage is 10,751 acre-feet (1986). The minimum total annual flow recorded at this gage is 3,648 acre-feet (1994). Figure 36 presents a graphical representation of this ditch’s mean and extreme annual flows in cfs.

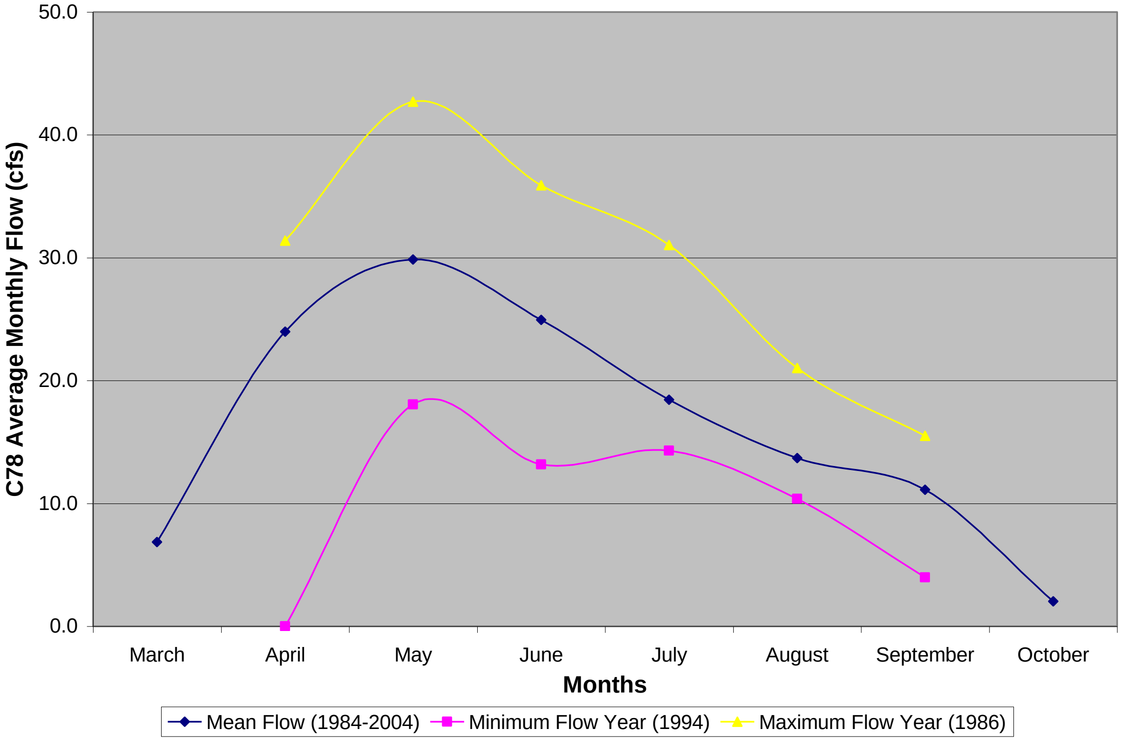


Figure 36. Mean, Minimum, and Maximum Annual Flows for C78 Fredricksburg Ditch

Records at this ditch were kept from March through October, with records for March only starting in 1997. The years 1986 and 1994 had neither March nor October records, thus their absence on the above graph. As with other diversion records, it is unclear whether prior to 1997 there was zero flow in Fredricksburg Ditch in March, or if record keeping for March started in 1999. Flow in this ditch was correlated to West Fork headwater flow minus the flow of the two Snowshoe Thompson ditches, the Heimsoth Ditch, and the McCollum Ditch. Regression analysis revealed well correlated natural log trend lines for June through September, and relatively poor trend lines for other months. There was no observable trend in March or October so those months are defined by their mean. Where regression results were used, R^2 values ranged from a low of 0.19 in April to a high of 0.67 for September. Results of the 1990-1999 simulation appear in Figure 37.

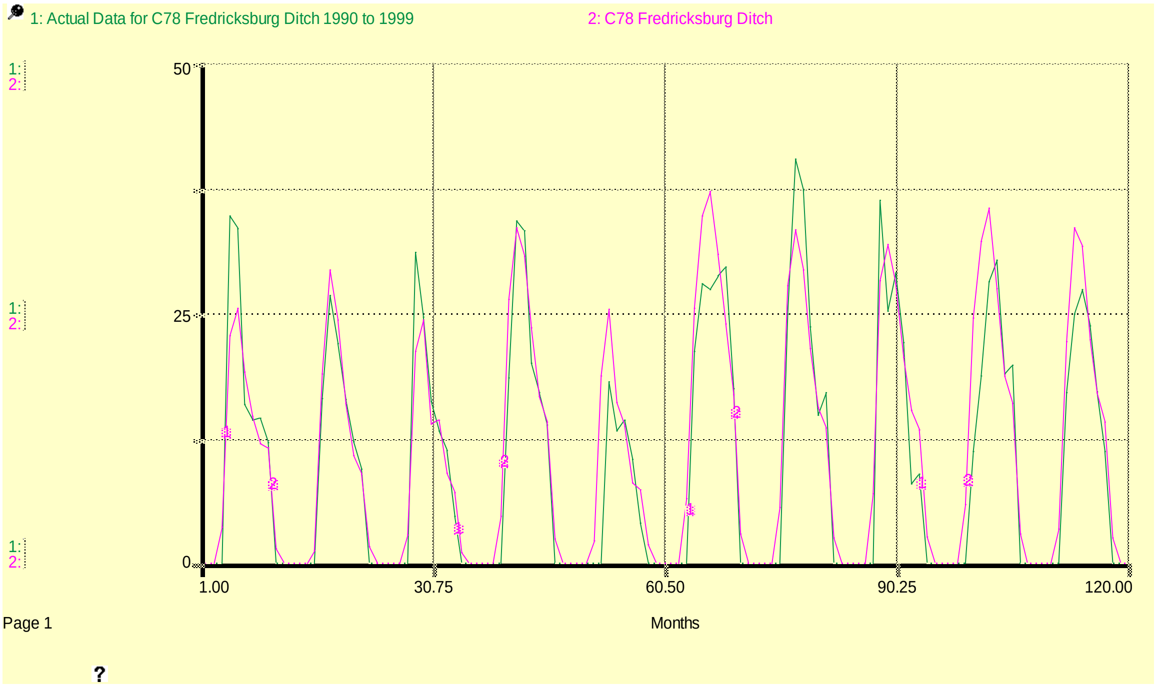


Figure 37. C78 Fredricksburg Ditch 1990-1999 Simulation, Actual vs. Model

Of particular mention is the model's under prediction of 1990 and 1996 and over prediction of 1995. Despite 1989-1990 being one of the lower precipitation winters in this data set, flow in Fredricksburg Ditch in 1990 is well above average. And the opposite is true for 1995. The spring of 1995 was one of the heaviest precipitation springs on record, yet Fredricksburg Ditch experienced lower flow than the drought years of 1990 to 1993. It appears that flow in Fredricksburg Ditch was occasionally negatively correlated to flow in the river in the 1990s, despite the fact that historically, a positive relationship between the two existed.

Fredricksburg Canyon Creek (Gage 10310300)

Fredricksburg Canyon Creek is a USGS gaged tributary to the Fredricksburg Ditch with a year round period of record of 1989-2001. Based on this record, the mean annual flow of this ditch is 3,130 acre-feet with a standard deviation of 2,176 acre-feet. The maximum total annual flow recorded at this gage is 8,526 acre-feet (1997). The minimum total annual flow recorded at this gage is 1,001 acre-feet (1992). Figure 38 presents a graphical representation of this creek's mean and extreme annual flows in cfs.

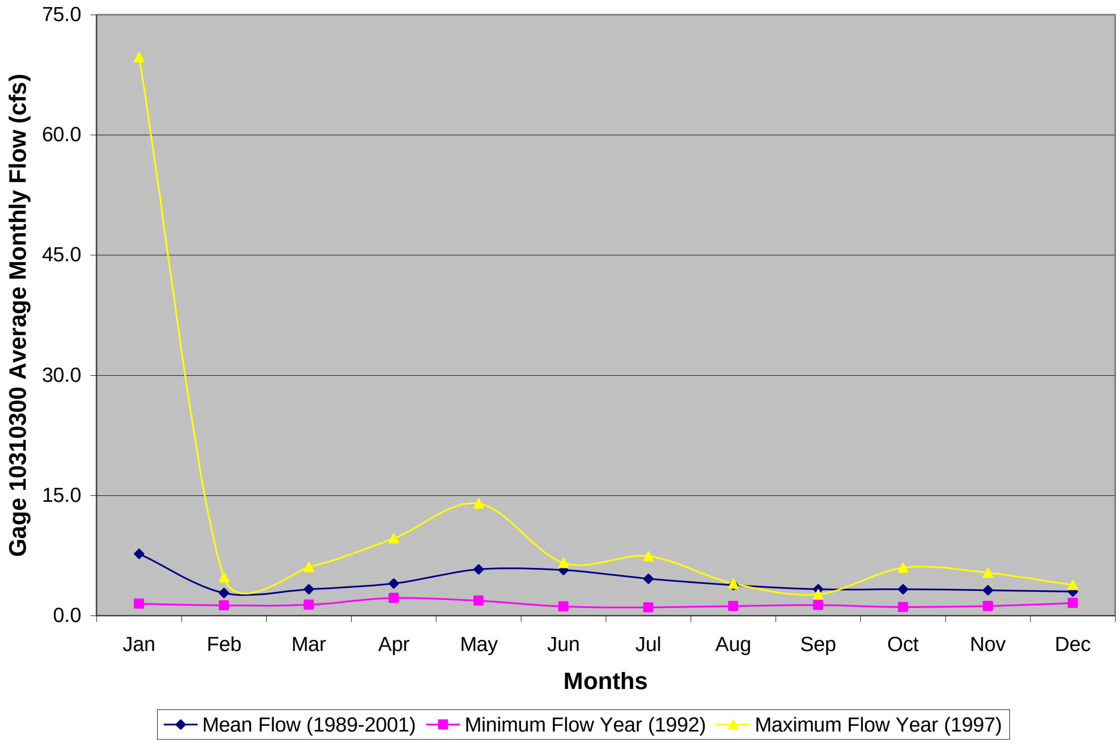


Figure 38. Mean, Minimum, and Maximum Annual Flows for Fredricksburg Canyon Creek (Gage 10310300)

Flow in this creek was correlated to West Fork headwater flow. Regression analysis revealed well correlated linear and natural log trend lines for all months, with R^2 values ranging from a low of 0.45 in March to a high of 0.99 in January. The R^2 value of 0.99 is not indicative of a perfect fit, but rather the result of the fact that the flood of 1997 made the data appear to fit very well. That is, due to the trend line being drawn directly to the flood data point, the other data points are off the trend by an amount that, relative to the flood data point, is miniscule. Results of the 1990-1999 simulation appear in Figure 39.

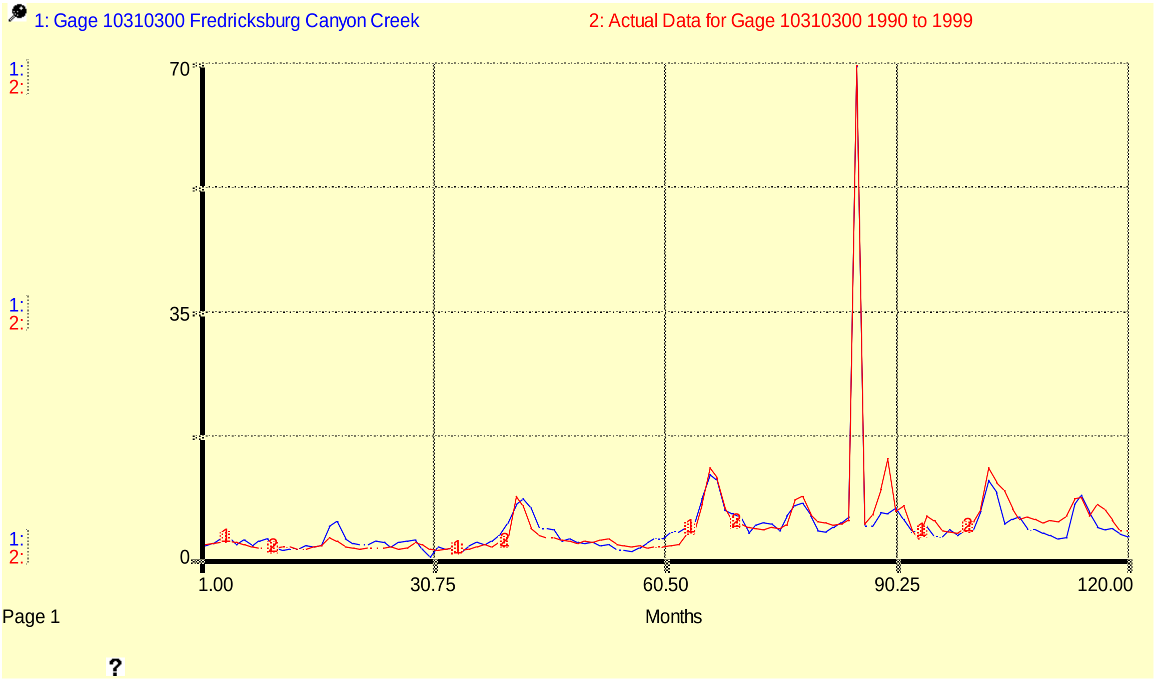


Figure 39. Fredricksburg Canyon Creek 1990-1999 Simulation, Actual vs. Model

Given the well correlated trend lines, the above results are expected. The model follows the actual data set quite well, notably the mirror of the flood of 1997.

C79 West Fork at Dressler Lane

The next gage on the West Fork occurs at Dressler Lane between Company Ditch and Dressler Ditch. This gage would have been quite useful in the model, as there is a lack of gages on the river and resultantly many diversions are based on flow many miles downstream. Unfortunately, some of data for this gage is considerably off. This was realized soon into the modeling, as flow at this gage was occasionally much greater or much lower than flow at the next gage, C80 Brockliss Slough at Ruhenstroth Dam, just two miles downstream. Problems with the gage on the Brockliss Slough were ruled out once a basic framework for the model was built, as the flow at the Dressler Lane gage did not correlate to the West Fork headwater gage during the same periods of non-correlation with the Brockliss Slough.

The other issue with this gage is that the gage is monitored as if it were a diversion and not a gage in the river: it is only monitored during the irrigation season. Of course, this is because the Federal Water Master and farmers in a general sense only have any appreciable concern for flow during the irrigation season. However, to planners and decision makers, and thus indirectly to farmers who may be affected by the decisions of planners and decision makers, having year round flow records where year round flow exists is of critical importance to understand the entire system. This issue and others will be discussed in greater detail in the Recommendations Section of this report. Despite the gage not being used, results of the 1990-1999 simulation appear in Figure 40, for the reader's benefit.

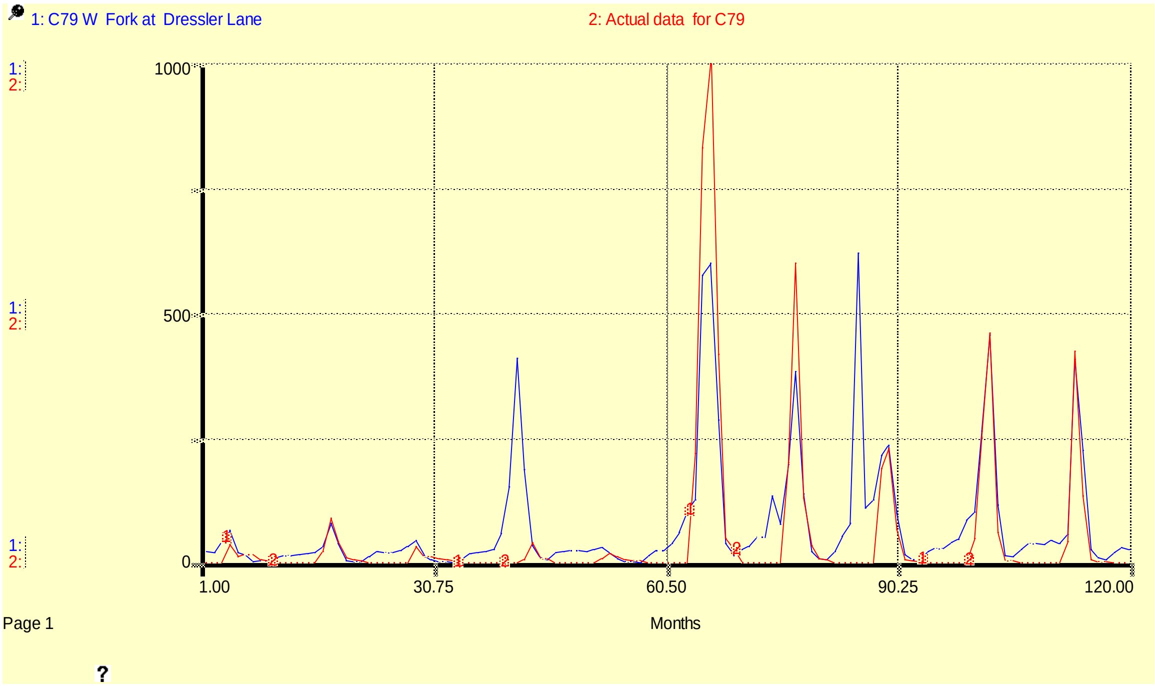


Figure 40. C79 West Fork at Dressler Lane 1990-1999 Simulation, Actual vs. Model

As one can see, there are time periods where the gage appears to be functioning correctly. Intermixed within this accurate data, however, is missing data that accounts for half of each year (October through March is largely missing, with only sporadic data recording in March and October) and entire irrigation seasons with inaccurate data (see 1993, 1995, and 1996).

2.3.3 The Brockliss Slough

C80 Brockliss Slough at Ruhenstroth Dam

Brockliss Slough at Ruhenstroth Dam is a Federal Water Master gaged “diversion” with a period of record of 1984-1986 and 1988-2004. As was previously discussed, the Brockliss Slough is not a diversion in the typical sense, but rather a complete diversion of the historic West Fork. Based on this historical record, the mean annual flow of the Brockliss Slough at Ruhenstroth Dam is 25,396 acre-feet with a standard deviation of 21,586 acre-feet. As evidenced by the large standard deviation, considerable flow variation is commonly observed at this site. As this is not a diversion, but rather the new West Fork, this is not that unusual as such variation also occurs at the West Fork’s headwater gage in Woodfords, CA. The maximum total annual flow recorded at this gage is 82,962 acre-feet (1995). The minimum total annual flow recorded at this gage is 1,078 acre-feet (1988).

Despite the fact that this gage is not recording a diversion, but rather the river, historical flows, unlike the headwaters or USGS gages in the river, do not include flows in November through February, and collection in March and October is sporadic. Thus, mean annual historical flows on the Brockliss Slough are, in reality, higher than the above figures.

The magnitude of difference between the two extreme annual flows on record (maximum annual flow is 77X greater than minimum annual flow) is extreme. This is because this gage has numerous diversions prior to it, unlike the West Fork headwater gage (maximum annual flow is 10X greater than minimum annual flow). Thus, the lowest year is close to zero because farmers were using nearly all the water that was available, and likely that wasn’t even enough. Figure 41 presents a graphical representation of this slough’s mean and extreme annual flows in cfs at this gage.

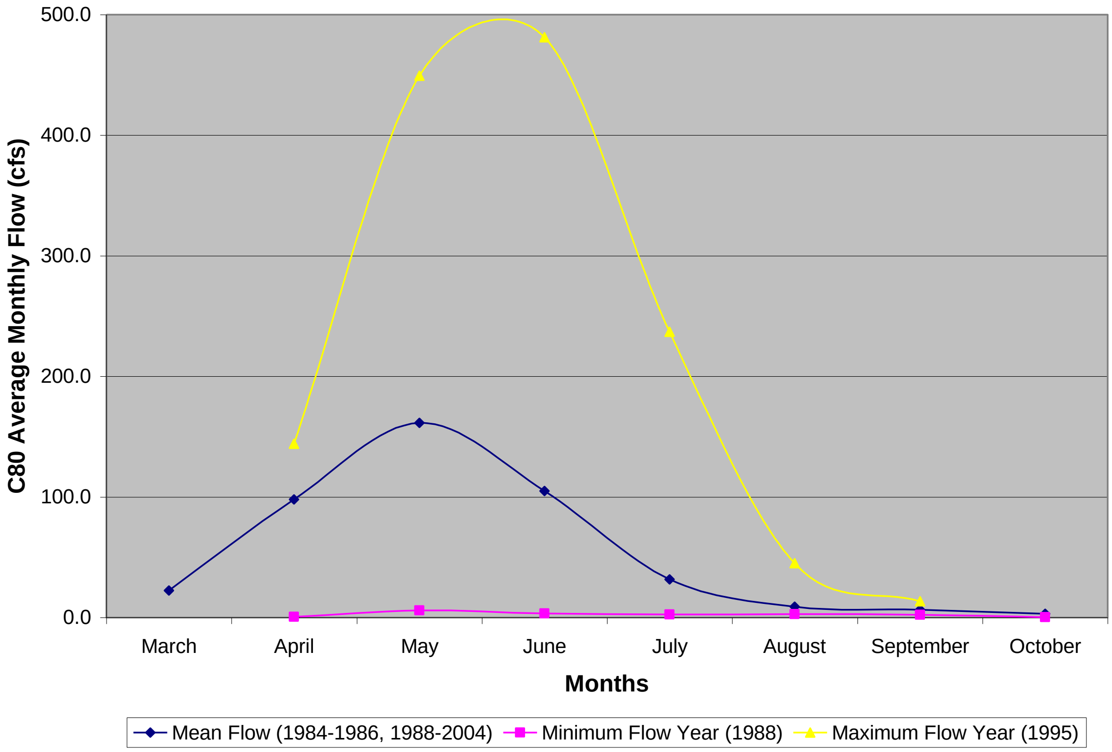


Figure 41. Mean, Minimum, and Maximum Annual Flows for C80 Brockliss Slough at Ruhenstroth Dam

Records at this ditch were kept from March through October, with March records only consistently kept since 2000. The year 1995 had no records for March or October and 1988 had no records for March, thus their absence on the above graph. Regression analysis was not used on this graph as the Brockliss Slough is not a traditional diversion. Instead, nearly 100% of the West Fork's flow was diverted into the Brockliss Slough in the model, with some minor amounts of spillover and return flow entering the historic West Fork. Results of the 1990-1999 simulation appear in Figure 42.

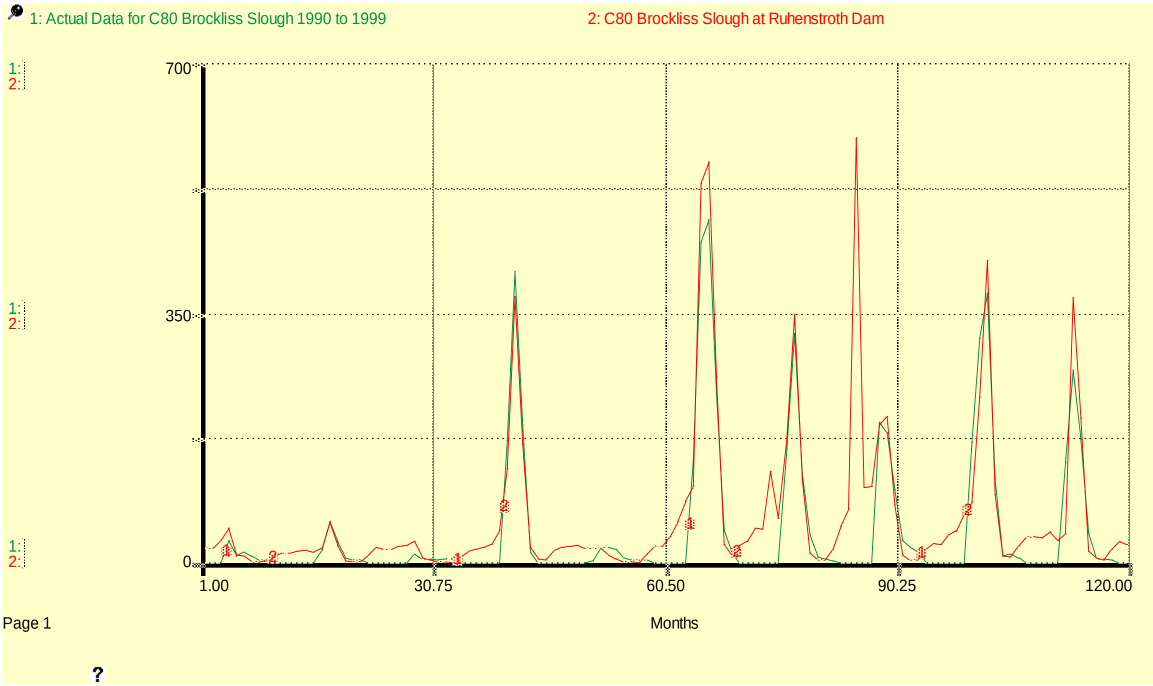


Figure 42. C80 Brockliss Slough 1990-1999 Simulation, Actual vs. Model

The model does quite well, with exception to somewhat over predicting 1995, 1998, and 1999. It was initially thought that this was due to some sort of breach in the channel at higher flows. However, 1993's flow was under predicted, which seems to invalidate this theory. The graph reveals the considerable lack of data that is lost as the result of collecting data only during the irrigation season. In particular, data for the January 1997 flood event would have been useful, as would data that would provide more knowledge of how successive drought or wet years and resultant aquifer depletion or recharge affect the following years' winter surface flow.

C81 Brockliss Slough at Scossa Box

Brockliss Slough at Scossa Box is a Federal Water Master gage on the Brockliss Slough approximately four miles past the Ruhenstroth Dam with a period of record of 1984-2004. As with the previous gage on the Brockliss Slough, data is only acquired for the irrigation season. Based on the historical record of the irrigation season, the mean annual flow of the Brockliss Slough at Scossa Box is 21,054 acre-feet with a standard deviation of 19,308 acre-feet. As with the Brockliss Slough gage at Ruhenstroth Dam, considerable flow variation is commonly observed at this site. The maximum total annual flow recorded at this gage is 72,948 acre-feet (1995). The minimum total annual flow recorded at this gage is 399 acre-feet (1988). Figure 43 presents a graphical representation of this slough's mean and extreme annual flows in cfs at this gage.

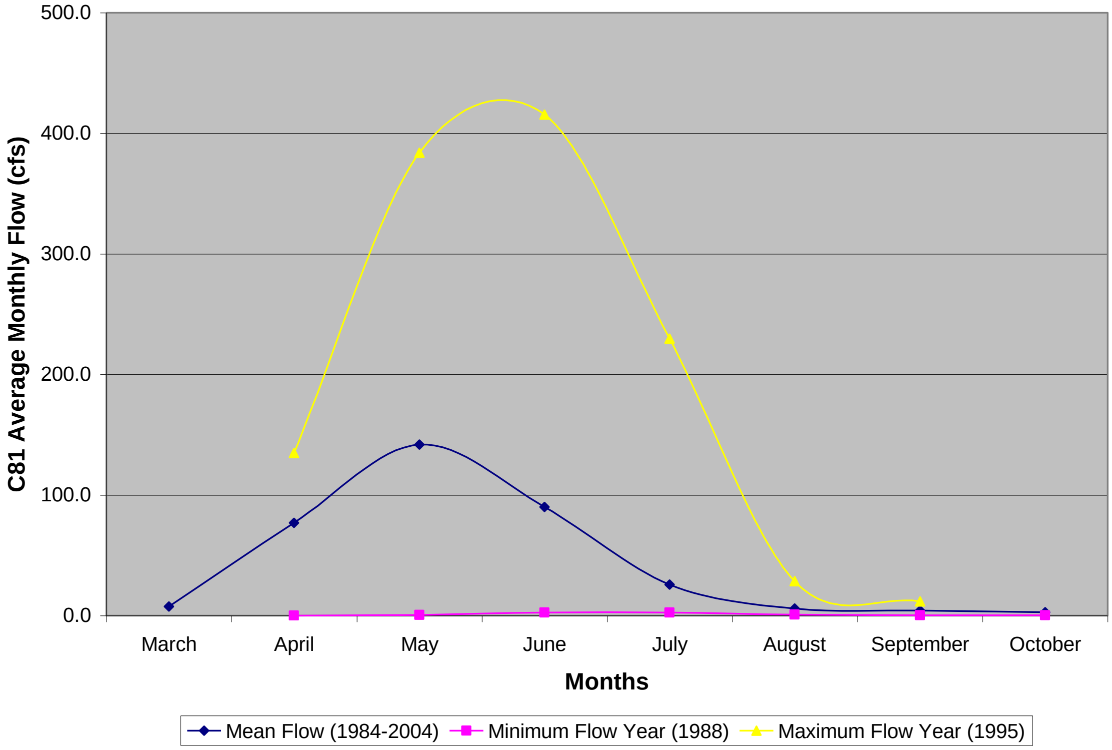


Figure 43. Mean, Minimum, and Maximum Annual Flows for C81 Brockliss Slough at Scossa Box

Records at this ditch were kept from March through October, with March records only consistently kept since 2000. The year 1995 had no records for March or October and 1988 had no records for March, thus their absence on the above graph. Flow in this ditch was correlated to C80 Brockliss Slough at Ruhenstroth Dam. Regression analysis revealed very well correlated linear trend lines for all months. This is likely due to the fact that this gage is not a diversion that is governed by water rights or ditch carrying capacity limits. R^2 values ranged from a low of 0.62 in October to a high of 0.98 for both July and August. Results of the 1990-1999 simulation appear in Figure 44.

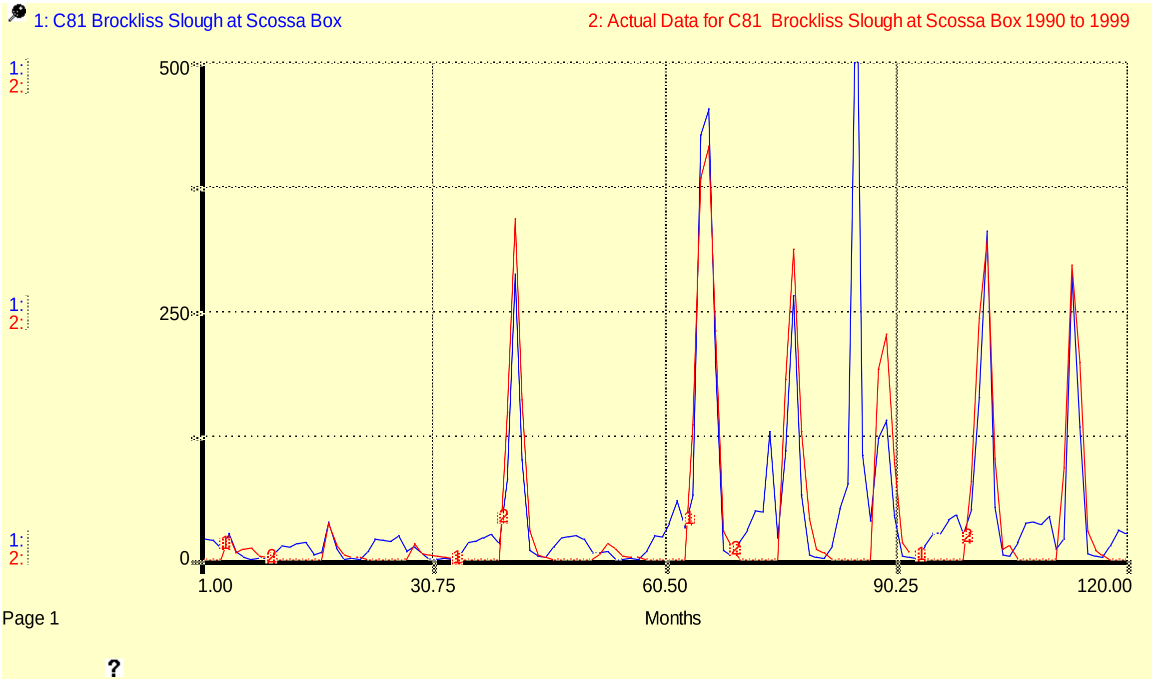


Figure 44. C81 Brockliss Slough at Scossa Box 1990-1999 Simulation, Actual vs. Model

The model does quite well, with exception to somewhat over predicting 1995 and under predicting 1993. As with the previous Brockliss Slough gage at Ruhenstroth Dam, the graph reveals the considerable lack of data that is lost as the result of collecting data only during the irrigation season.

Gages 10310402 and 10310403: Lower and Upper Brockliss Sloughs

Shortly after the previous gage, the Brockliss Slough splits into two distinct segments, the Upper (West) Brockliss Slough and the Lower (East) Brockliss Slough, both of which are USGS gaged. The Upper Brockliss Slough is the larger of the two segments. Gage 10310402 in on the Lower Brockliss Slough and Gage 10310403 is on the Upper Brockliss Slough. Data at both of these gages data is recorded year round. Unfortunately however, both gages have very limited periods of record: 1995-1998. Because of this, and the fact that the brief period of record consists entirely of wet years, providing existing statistics as historic records for these gages is inappropriate.

This portion of the Upper Carson River Basin was the most difficult to model for numerous reasons. First, the lack of a reasonable historical record was problematic in that it was difficult, if not impossible, to ascertain what a normal or low precipitation year would actually look like. Secondly, the gage that would have been most appropriate to correlate flow to via regression analysis, C81 Brockliss Slough at Scossa Box, is limited to irrigation season data only, whereas the gages on the Upper and Lower Brockliss Sloughs have year round data. Because these gages represent the only gages on the Brockliss Slough to have year round data, it is important that these months be included in the model. The gage previous to C81, C80 Brockliss Slough at Ruhenstroth Dam, could also have been used for regression analysis, however, the Ruhenstroth Dam gage only has data for the irrigation season as well.

Lastly, the flow of the Upper Brockliss Slough alone exceeds the recorded flow of C81 Brockliss Slough at Scossa Box, thus there are obviously other sources of flow contributing to one or both of these segments of the Brockliss Slough. A graph of average flows for C81 Brockliss Slough at Scossa Box and the Upper and Lower Brockliss Sloughs illustrates this problem. The graph shows only that period of record that is common for all three gages (March-October, 1995-1998).

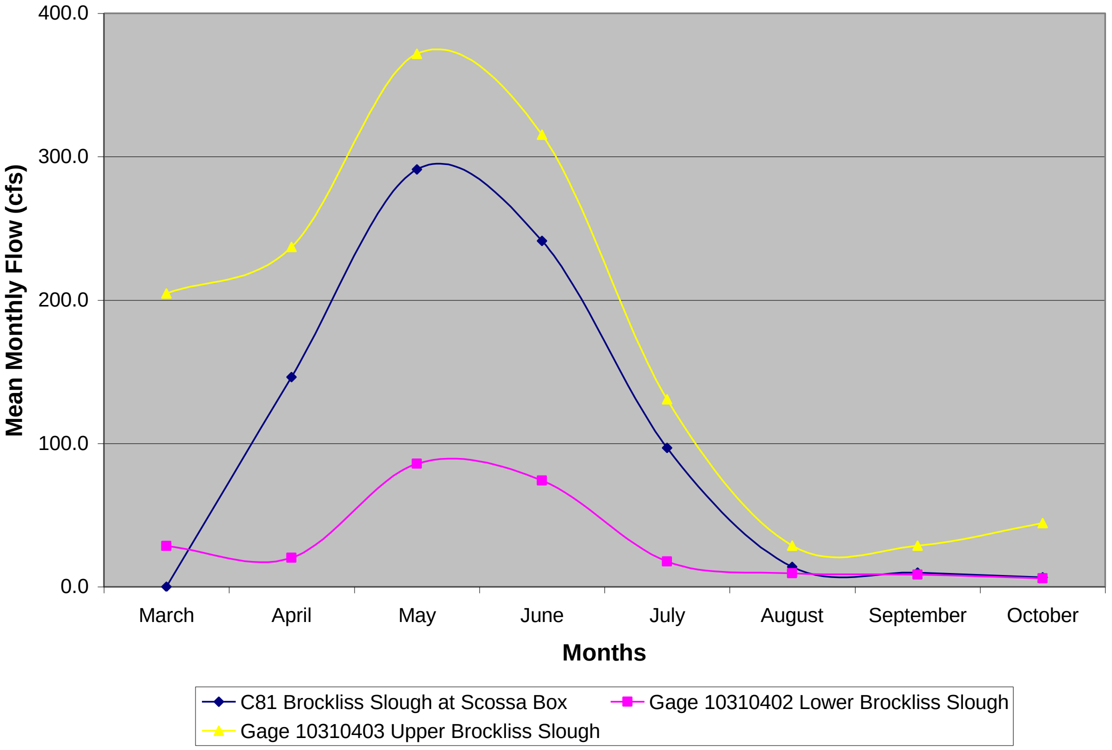


Figure 45. Mean Monthly Flows for C81, Gage 10310402, and Gage 10310403, Period of Record 1995-1998.

To predict flow at these gages, many different concepts were formulated and tried in the model. In the end, a combination of groundwater and tributary flow was found to yield the best results for the 1990-1999 simulation (of which only 1995-1998 are available for comparison), and in theory, was thought to be the most representative of the flow regimes present there.

The Carson Range, which borders the Upper Brockliss to the west, has a number of mostly ungaged tributaries flowing off its east slopes toward the Upper Brockliss Slough. These tributaries include Genoa Canyon Creek, Daggett Creek, Mott Canyon Creek, Monument Creek, Stutler Creek, Sheridan Creek, Jobs Canyon Creek, Miller Spring, and Luther Creek. The latter two tributaries are slightly south of the Brockliss, but are nevertheless included here because it is assumed that surface and subsurface flow in that portion of the valley would eventually transport the two tributaries' surface and subsurface flow to the Brockliss Slough.

Recent studies by Maurer et al. (2004) revealed significant tributary flow entering the Carson Valley. Maurer et al. (2004) estimated this total flow to be approximately 37,600 acre-feet/year. Using data from that study, the following table was created that specifically details the estimated annual flow of only the streams that are likely impacting the Brockliss Slough.

Table 7. Estimated Flow from Selected Tributaries in the Carson Range (Maurer et al., 2004)

Tributary	Estimated Annual Flow (acre-feet)
Genoa Canyon Creek	960
Daggett Creek	1200
Mott Canyon Creek	1700
Monument Creek	2600
Stutler Creek	450
Sheridan Creek	1300
Jobs Canyon Creek	1700

Miller Creek	630
Luther Creek	2200
Total Annual Acre Feet	12740

The objective was to represent the above tributary flow regime off the Carson Range in the model. Following the tenants of Occam's razor, this was first attempted by defining the above collective tributary flow as a percentage of the West Fork headwater gage. This assumed that all of the tributaries and West Fork have the same exact runoff curve. In his study of Carson tributary flow, Maurer et al. (2004) estimated the mean monthly flow and runoff curves for every tributary. While the runoff curves varied widely, a common trait of nearly all of the tributaries was evident. Annual flow over the course of a year resembled more of a bell curve than the typical run-off curve for the Upper West Fork. Thus, the collective tributary flow was defined as a percentage of the West Fork headwater flow, and code was put into the model which flattened out the headwater runoff curve, and generalized the common flow regime of the above nine tributaries.

If the above total acre feet figure of 12,740 is put in context with the average annual total acre feet of the West Fork headwater gage at Woodfords, CA, for the same time period (1990-2002) it is found that annual flow for the above tributaries comprise an average of 17% of annual flow from the West Fork headwater gage. Obviously, 100% of the tributary flow is not reaching the Upper Brockliss Slough. However, the losses are mitigated by other significant sources of flow. One, there are likely many smaller tributaries that transport water down the eastern slopes of the Carson Range to the Upper Brockliss Slough. Two, there is likely significant groundwater flow occurring below the surface water runoff along the Carson Range.

From a systems approach then, with all of the above in mind, using a figure of 17% of the West Fork headwater gage is a simple and fairly accurate way to represent Carson Range tributary flow into the Upper Brockliss Slough. Yet when this process was incorporated into the model, flow in the Upper Brockliss was still deficient. To remedy this, the percentage was increased by another 5%, as it was apparent that there was more groundwater flowing beneath the stream flows than the 17% accounted for. The addition of this tributary ground and surface water flow, combined with the direct and indirect routing of groundwater flow from the Fredricksburg Ditch and other ditches that feed surface and subsurface flow into the Upper Brockliss Slough, was selected for the sake of simplicity, gage accuracy, and its approximate representative depiction of the various flow regimes present at this location. Of course, all the tributaries do not enter the Brockliss at the same location. For model purposes, though, a single point of entry is acceptable. Figures 46 and 47 illustrate the modest success of this approach.

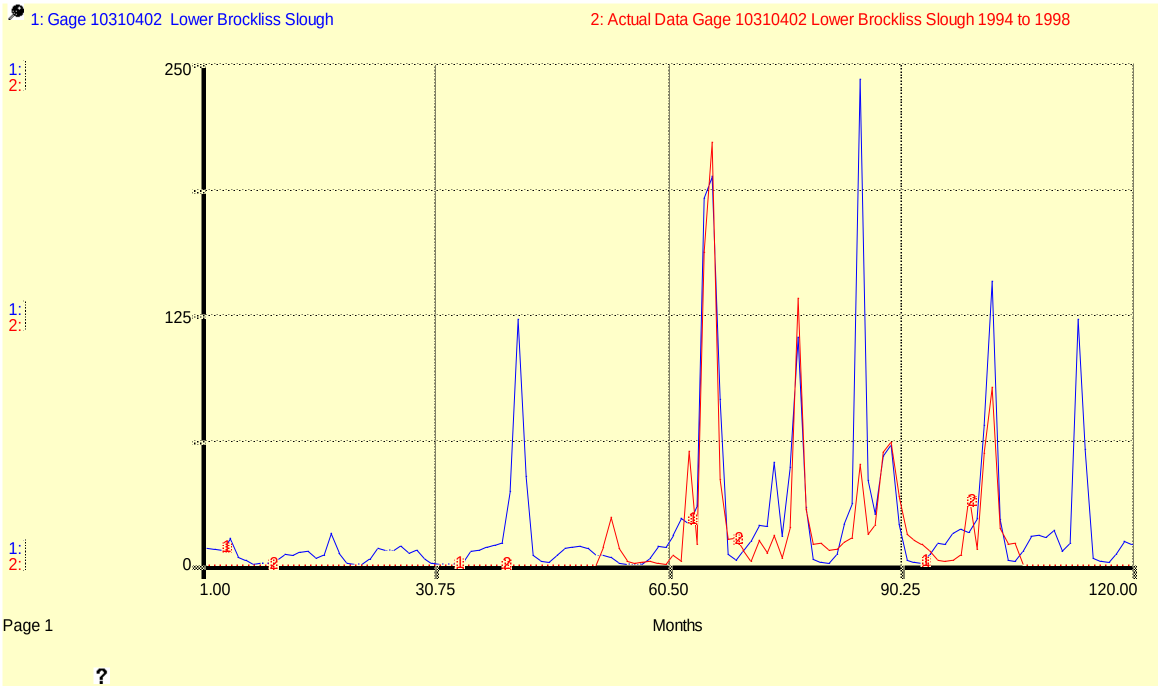


Figure 46. Gage 10310402 Lower Brockliss Slough 1990-1999 Simulation, Actual vs. Model

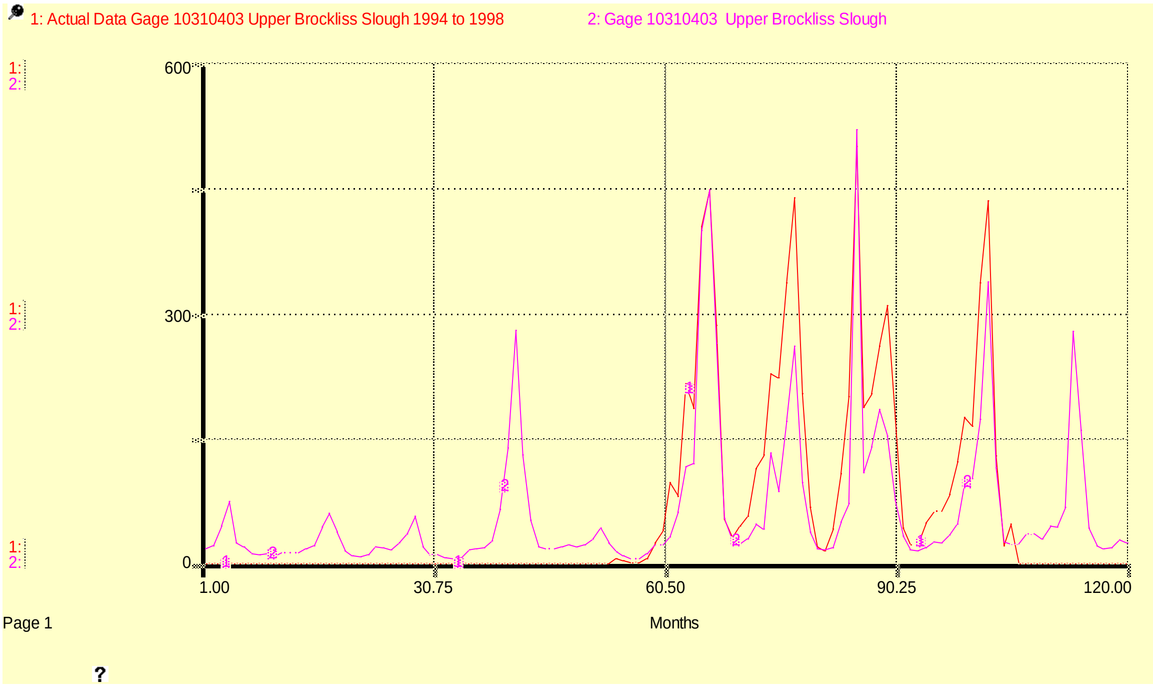


Figure 47. Gage 10310403 Upper Brockliss Slough 1990-1999 Simulation, Actual vs. Model

As one can see, the results are far from stellar. Notable problem areas in the model simulation of the Upper Brockliss Slough are the under prediction of peak flow in 1996-1998. Given the difficulties involved, however, this model prediction is moderately successful. Conversations with various individuals familiar with these reaches have confirmed that some of these recorded historical flows may not be as high as the data suggests due to possible errors in the rating curves. It was suggested that because the river occasionally backs up near those gages, the height of the river may be not indicative of increased flow (as the rating curve would suggest), but rather a function of stalled flow. Thus, the model depictions may be more accurate than the data suggests. It is certainly difficult to believe from a hydrologic standpoint, that the quantity of water still lacking in this reach during the aforementioned time periods is even capable of entering the Upper Brockliss, given the large quantities of water already added to the system via groundwater and tributary flow.

Problem areas in the Lower Brockliss Slough include the extreme over prediction of the flood of 1997, and the under prediction of 1998. The over prediction of the 1997 flood event is not of critical importance, because the likely scenarios that will be run using this model do not include forecasting flood events. Even if the scenarios were concerned with such events, the concern would likely lie in the net effect of the flood: how much water makes it to Lahontan Reservoir. While this particular modeled gage over predicted the 1997 flood event, the gages of more importance to decision makers, the Main Carson River gages near Carson City and near Dayton prior to Lahontan Reservoir, still somewhat under predicted the flood.

This gage's specific over prediction of the flood is indicative of not having enough specificity to the model so that flood waters could be transported to the river from this specific area in the valley. The overall under prediction of the flood (near Carson City and Dayton) is likely due to the model's lack of specificity with respect to very small tributaries that, in other more normal scenarios, contribute very negligible amounts of flow to the system, but during times of extreme flooding, can collectively carry significant portions of flood water. The under prediction of 1998 is somewhat troubling. However, without much more data and assurances that the existing small data set is reliable, attempting to determine the source of error for that year, if there is any error, does not seem prudent.

Main Brockliss Tributary Inflow

There are other tributaries that flow into the Brockliss Slough after the Upper and Lower Brockliss Sloughs converge east of Genoa, NV. These include James Canyon Creek, Water Canyon Creek, and Sierra Canyon Creek. Maurer et al. (2004) also studied these tributaries. Their average flows are listed in Table 8.

Table 8. Estimated Flow from Selected Tributaries in the Carson Range (Maurer et al., 2004)

Tributary	Estimated Annual Flow (acre-feet)
James Canyon Creek	1300
Water Canyon Creek	630
Sierra Canyon Creek	2200
Total Annual Acre Feet	4130

Using the same logic and assumptions as stated earlier, these streams were calculated to contribute an average of 5.5% of the West Fork's headwater gage. As with the above tributary flow, in the model this percentage was slightly increased and the runoff curve was flattened out to more resemble the specific tributaries involved.

Major Ungaged Ditches and Sloughs that Feed the Brockliss Slough

There are many ditches that traverse the irrigated fields to the west of the West Fork and Brockliss Slough. These ditches are largely fed by ground and surface water flows that stem from the Fredricksburg Ditch, the Brockliss Slough, and the Carson Range to the west. Only the main ditches are herein discussed. They include Big Ditch, Big Slough, Johnson Ditch, and Park and Bull Ditch.

Big Ditch and Big Slough rely on return flows from upstream ditches such as Fredricksburg Ditch and Thran Ditch. Return flows from Big Ditch as well as other upstream ditches supply flow to Johnson Ditch and Park and Bull Ditch. The latter two ditches eventually return their flow back to the Brockliss Slough. In the model, return flow from these ditches is used to augment flow in the Upper Brockliss Slough, discussed above.

2.3.4 East Fork Carson River

East Fork Headwaters (Gage 10308200)

The East Fork headwaters originate high in the Sierras at an elevation over 11,000 feet (Horton, 1997b), approximately 2,500 feet higher than the origin of the West Fork. For modeling purposes, the East Fork begins at Gage 10310000 located northeast of Markleeville, CA, at an elevation of 5,400 feet, over one mile lower than its headwaters. Gage 10308200 has a significant period of record: 1961-current (2003), however, it is not as long as the West Fork's headwater gage, nor the next downstream gage, Gage 10309000, which both have consistent periods of record from 1940. This issue is likely the reason that the majority of other studies refer to Gage 10309000 as the East Fork headwater gage. Gage 10309000 is not, however, the headwater gage. Thus this report refers to Gage 10308200 as the East Fork headwater gage.

Based on the above period of record, the mean annual flow from the East Fork headwater gage is 259,151 acre-feet with a standard deviation of 128,583 acre-feet. As evidenced by the large standard deviation, considerable flow variation is commonly observed at this site. The maximum total annual flow recorded at this gage is 595,951 acre-feet (1983). The minimum total annual flow recorded at this gage is 61,862 acre-feet (1977). Figure 48 presents a graphical representation of the East Fork headwaters' mean and extreme annual flows in cfs.

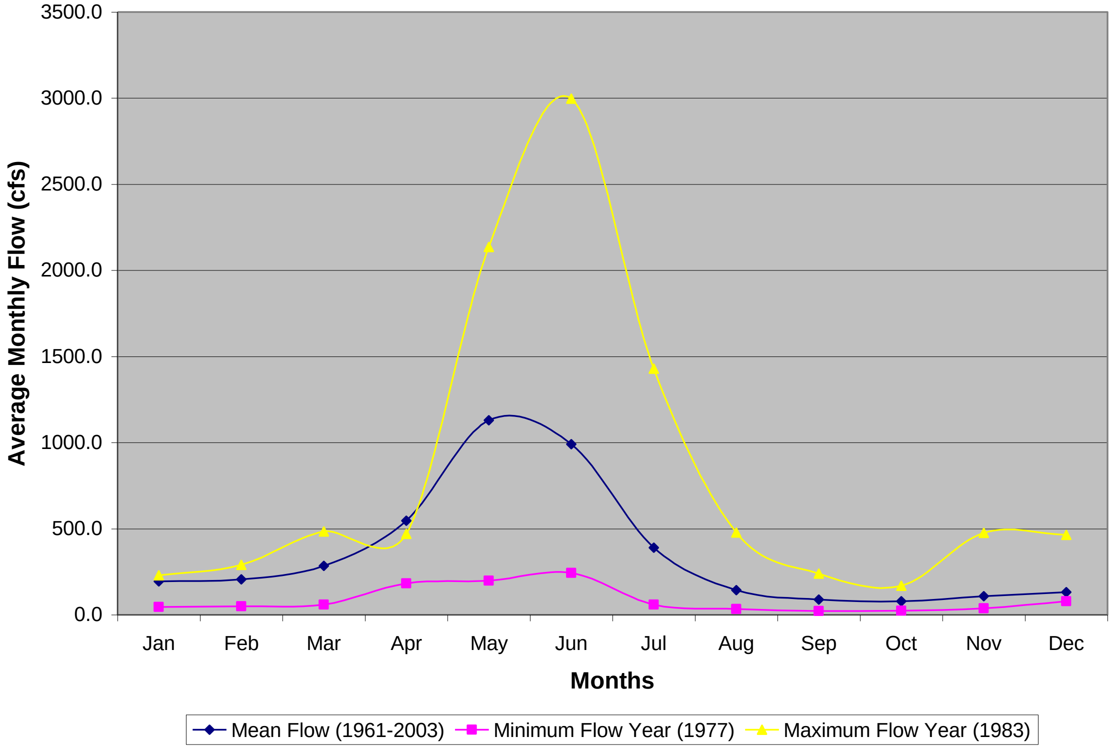


Figure 48. Mean, Minimum, and Maximum Annual Flows for East Fork Headwaters (Gage 10308200)

As with the West Fork headwater gage, this gage is controlled by precipitation in the model.

Bryant Creek (Gage 10308800)

Bryant Creek is a USGS gaged East Fork tributary with a year round period of record of 1962-1968, 1978-1979, and 1995-2003. Based on this record, the mean annual flow of this creek is 5,528 acre-feet with a standard deviation of 3,289 acre-feet. The maximum total annual flow recorded at this gage is 13,862 acre-feet (1995). The minimum total annual flow recorded at this gage is 2,234 acre-feet (2001). Figure 49 presents a graphical representation of this creek's mean and extreme annual flows in cfs.

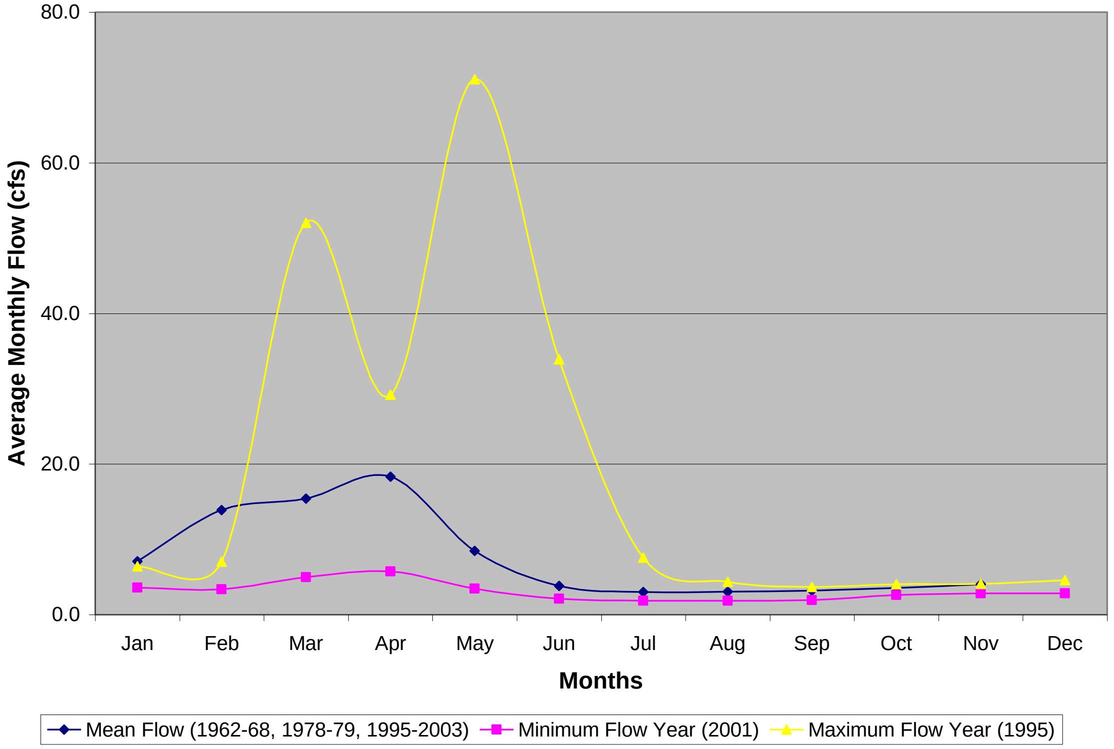


Figure 49. Mean, Minimum, and Maximum Annual Flows for Gage 10308800 Bryant Creek

Flow in this creek was correlated to East Fork headwater flow. Regression analysis revealed well correlated linear and natural log trend lines for all months spare November, which had the lowest R^2 of 0.32. Discounting November's anomaly, R^2 values ranged from a low of 0.57 in October to a high of 0.97 in January. Results of the 1990-1999 simulation appear in Figure 50.

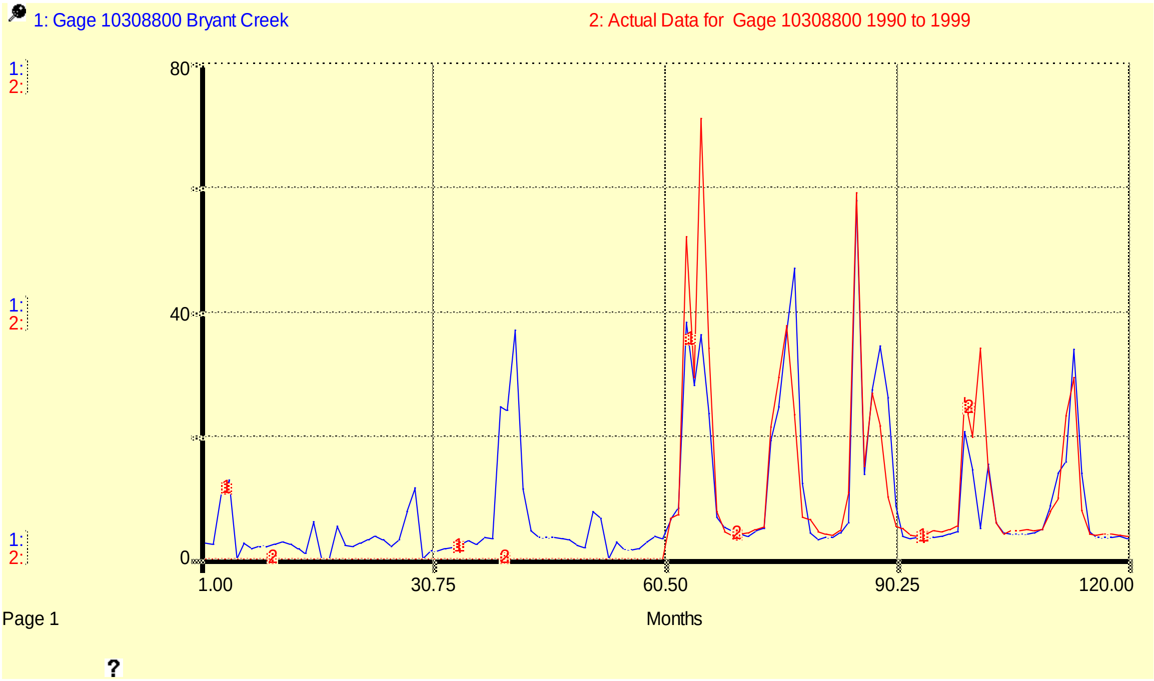


Figure 50. Gage 10308800 Bryant Creek 1990-1999 Simulation, Actual vs. Model (Only 1995-1999 Actual Data Available)

Despite the well correlated trend lines, there are a few inconsistencies in the short period of record above. Of particular notice are the abnormalities of 1995 and 1998. Both 1995 and 1998 were abnormal in that there was excessive winter precipitation late in the spring. March through June of 1995 were well above normal monthly precipitation averages in the Sierras and May and June of 1998 were above normal monthly precipitation averages as well. Headwater flow on the East Fork typically peaks in May and by July flow is typically a third of what it was in May. However in 1995 and 1998, heavy late spring snowfall caused the runoff in both June and July to exceed that of May, due to colder temperatures and less sunshine in May because of the falling snow in the mountains. The gage at Bryant Creek, however, despite being at the same elevation as the gage to which it is correlated (Gage 10308200), still experienced its peak runoff in May. This was likely due to differences in sun exposure and/or differences in temperature that caused the precipitation that fell as snow south of Markleeville to fall as rain near the state line. So what appears as an ideal correlation can lead to interesting results when uncommon events occur. Predicting the results of such an unusual event is not one of the objectives of this model. As was discussed earlier, this model is geared toward long term policy decisions, not predicting the ramifications of varying snow levels for different mountain ranges.

East Fork between the State Line and Dresslerville (Gage 10309000)

This East Fork river gage has the oldest period of record in the basin: 1890-1893, 1901-1903, 1908-1910, 1925-1927, and 1940-current (2003). As was discussed above, many other studies refer to this gage as the East Fork Headwaters, despite the fact that it is some fifteen miles downstream of the actual headwater gage. Based on this record, the mean annual flow of this East Fork at Gage 10309000 is 282,170 acre-feet with a standard deviation of 132,320 acre-feet. The maximum total annual flow recorded at this gage is 692,057 acre-feet (1890). The minimum total annual flow recorded at this gage is 66,180 acre-feet (1977). Figure 51 presents a graphical representation of this reach of the river's mean and extreme annual flows in cfs at this gage.

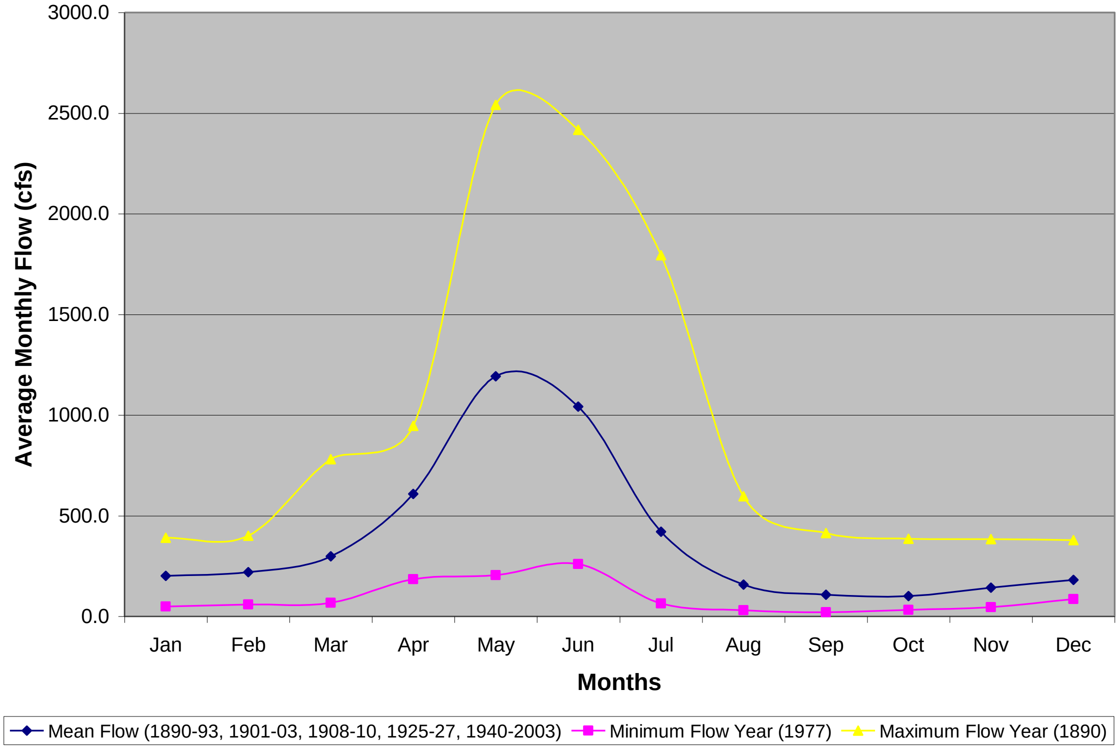


Figure 51. Mean, Minimum, and Maximum Annual Flows for Gage 10309000 East Fork Carson River

Flow recorded at this gage was correlated to East Fork headwater flow plus inflow from Bryant Creek. Regression analysis revealed extremely well correlated linear trend lines for all months. R^2 values ranged from a low of 0.97 in October to a high of 0.99 in July. Results of the 1990-1999 simulation appear below. The high degree of correlation is because flow between the headwater gage and Gage 10309000 is largely uninterrupted, with the only major inflow/outflow being inflow from Bryant Creek.

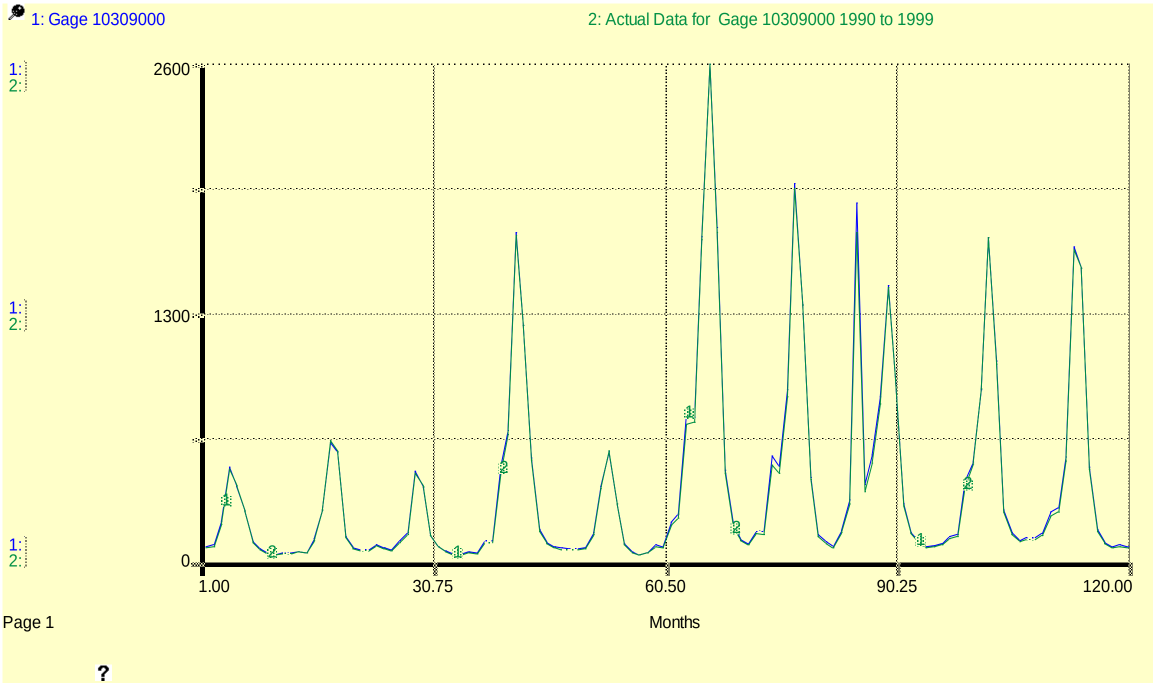


Figure 52. Gage 10309000 East Fork Carson River 1990-1999 Simulation, Actual vs. Model

C82 Allerman Canal

The first major diversion the East Fork supplies is the basin's largest diversion, the Allerman Canal, which carries flow to the north and feeds a number of other largely ungaged ditches. The Allerman Canal is a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this canal is 24,974 acre-feet with a standard deviation of 5,068 acre-feet. The maximum total annual flow recorded at this gage is 38,761 acre-feet (1995). The minimum total annual flow recorded at this gage is 17,912 acre-feet (1987). Figure 53 presents a graphical representation of this canal's mean and extreme annual flows in cfs.

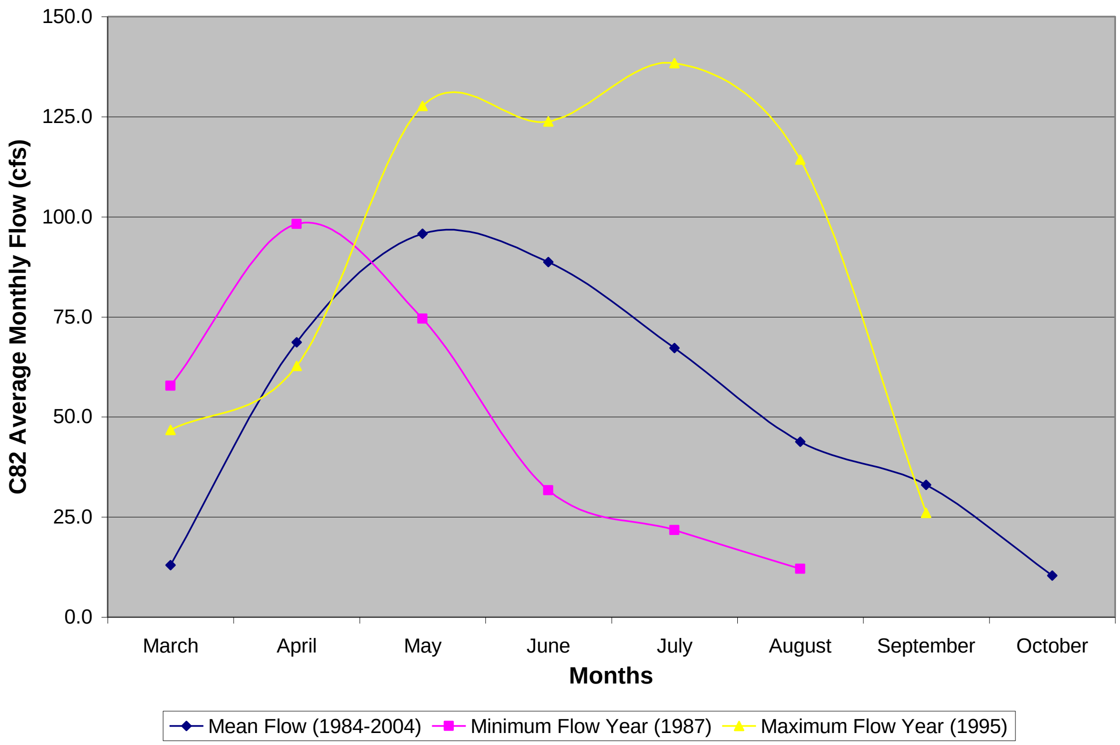


Figure 53. Mean, Minimum, and Maximum Annual Flows for C82 Allerman Canal

Records at this ditch were kept from March through October, with records for March only consistently available since 1991. Flow in this canal is correlated to flow at the previous gage, Gage 10309000. Regression analysis revealed well correlated linear and natural log trend lines for July through October, and relatively poor trend lines in other months. There was no observable trend in March or April so those months are defined by their diversion rate mean. R^2 values ranged from a low of 0.23 for May to a high of 0.93 for August.

The Allerman Canal is specifically governed by the Alpine Decree, as described in Section 3.3. For modeling purposes, it was found that a regression relationship achieved more accurate results than the use of IF THEN ELSE logic that mimicked the Alpine Decree. Because the Alpine Decree logic (when flow at the Gardnerville Gage reduces to 200 cfs, 1/3 of the East Fork's flow is directed into the Allerman Canal) does not necessarily begin at the beginning of a month, but rather at any time during the month, the use of such IF THEN ELSE logic in the model produced less accurate results. Thus, the choice to use regression was made. Realistically, the regression method inherently takes into consideration the Alpine Decree logic, as it is correlated to flow at the Gardnerville Gage. Results of the 1990-1999 simulation appear in Figure 54.

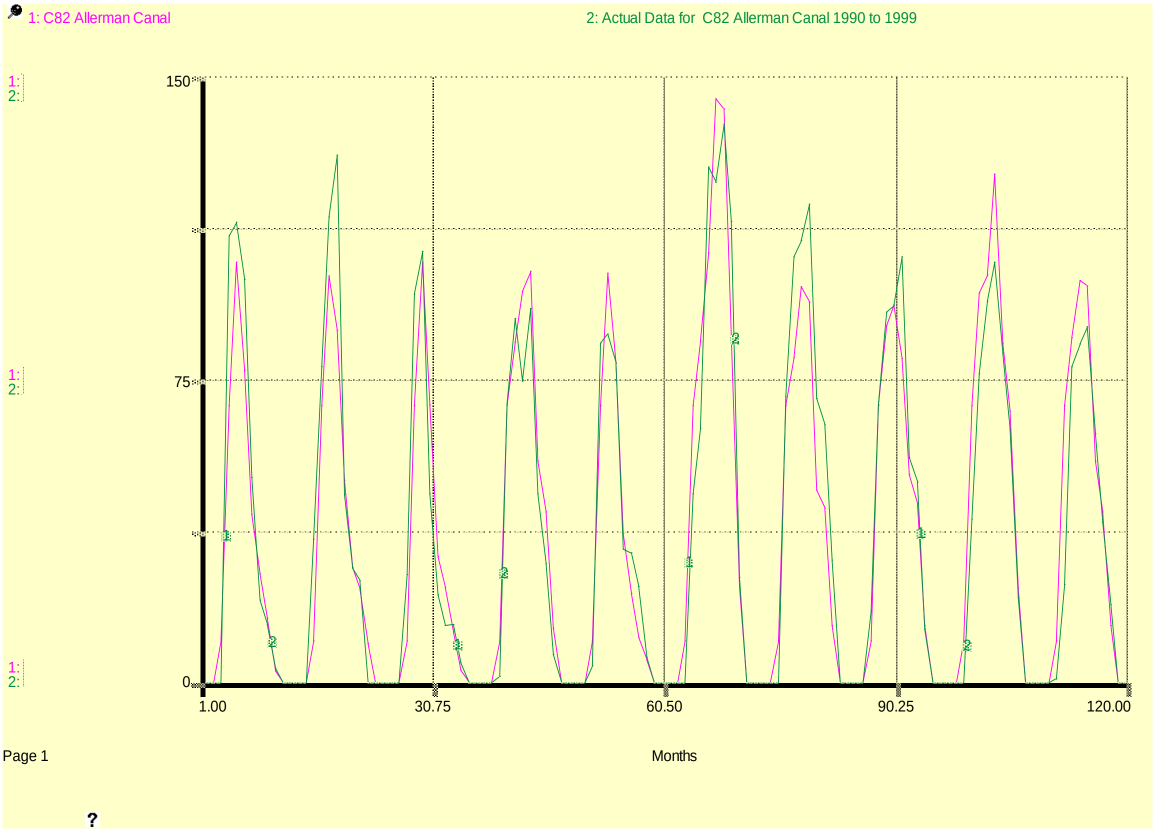


Figure 54. C82 Allerman Canal 1990-1999 Simulation, Actual vs. Model

The model under predicts many of the years, including 1990, 1991 and 1996. Despite these years being drought years, flow in the Allerman Canal during this time is above normal. The under prediction is likely related to the water table being rather low for these years due to the drought. The Allerman Canal is known to have high transmission losses (J. Larrouy, personal communication, 2005) and this condition is likely exacerbated during extended periods of drought. So when the soil beneath the canal is drier, more water is required in the canal to supply irrigators with the water they desire, as more canal flow is being lost to groundwater infiltration. The rest of the decade is predicted quite well, with exception to 1996.

Taking a closer look at the actual data from 1996 (see Appendix B) reveals that year to be somewhat of an anomaly in that, other than 1995, it is the only year to have three successive months of flow over 100 cfs. Also unusual in 1996 is the fact that flow in the Allerman Canal peaked in July, as opposed to May (normal peak) or June.

Gaged Tributaries to the Allerman Canal: Pine Nut Creek and Buckeye Creek

Pine Nut Creek and Buckeye Creek are two main tributaries that run off the Pine Nut Mountains east-southeast of the Carson Valley. Both creeks are USGS gaged with identical historical records of 1981-1996. Based on these records, the mean annual flow of Pine Nut Creek is 921 acre-feet with a standard deviation of 892 acre-feet. Pine Nut Creek's maximum total annual flow occurred in 1983 (3,642 acre-feet) and its minimum total annual flow occurred in 1992 (211 acre-feet). The mean annual flow of Buckeye Creek is 622 acre-feet with a standard deviation of 712 acre-feet. Buckeye Creek's maximum total annual flow occurred in 1983 (1,999 acre-feet). According to historical records, Buckeye Creek often runs nearly dry for extended periods of time, even for as long as a year. Such near-dry years occurred in 1981, 1990, 1992, and 1994. See Figures 55 and 56 for Pine Nut and Buckeye Creek's mean and extreme annual flows in cfs.

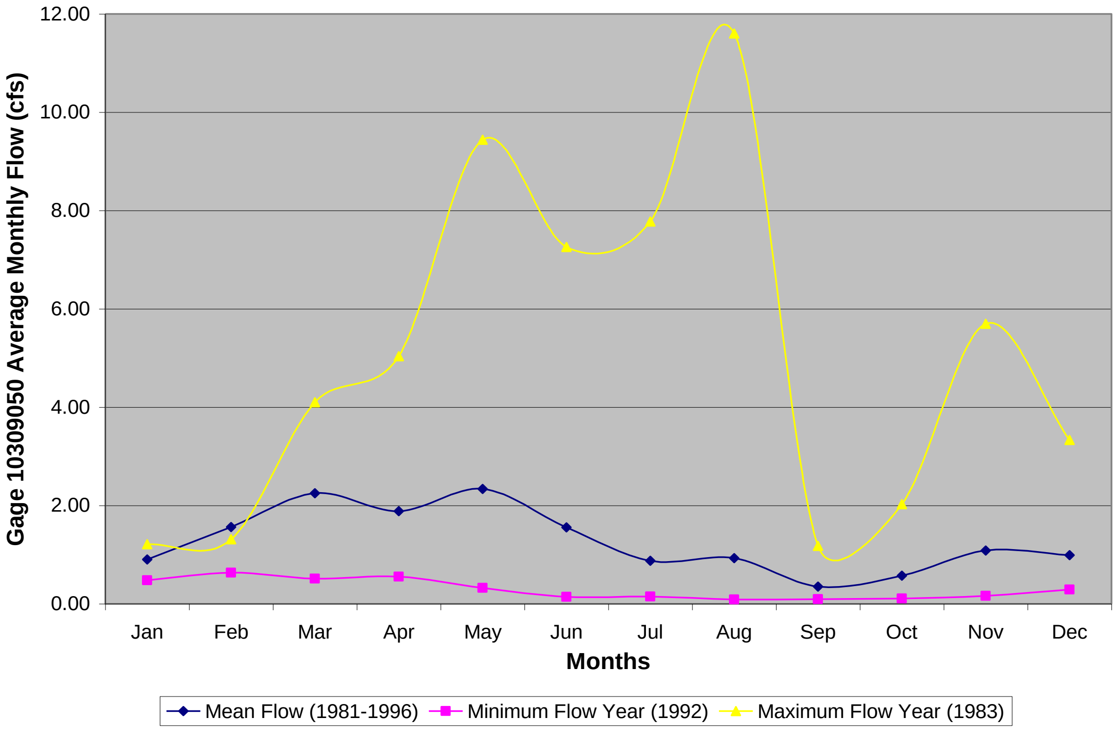


Figure 55. Mean, Minimum, and Maximum Annual Flows for Pine Nut Creek (Gage 10308050)

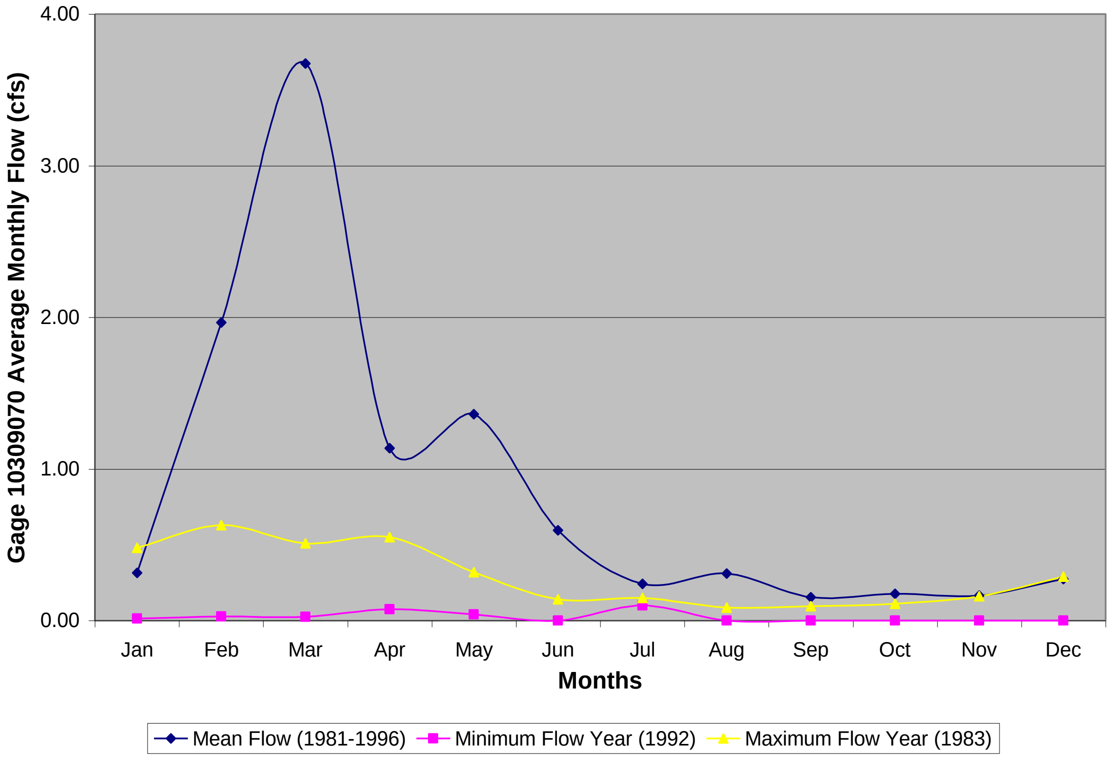


Figure 56. Mean, Minimum, and Maximum Annual Flows for Buckeye Creek (Gage 10308070)

Both Pine Nut Creek and Buckeye Creek flows are correlated to the East Fork headwater Gage, as this gage most closely resembles the elevation of the two creeks. Regression analysis revealed fairly well correlated linear and natural log trend lines for most months of Pine Nut Creek with R^2 values ranging from a low of 0.36 in September to a high of 0.84 in February. Buckeye Creek did not correlate as well due to the many years of extremely low flow. R^2 values for Buckeye Creek ranged from a low of 0.18 in September to a high of 0.95 in January. Results of the 1990-1999 simulation appear in Figures 57 and 58. Both creeks only have available data from 1990 to 1996.

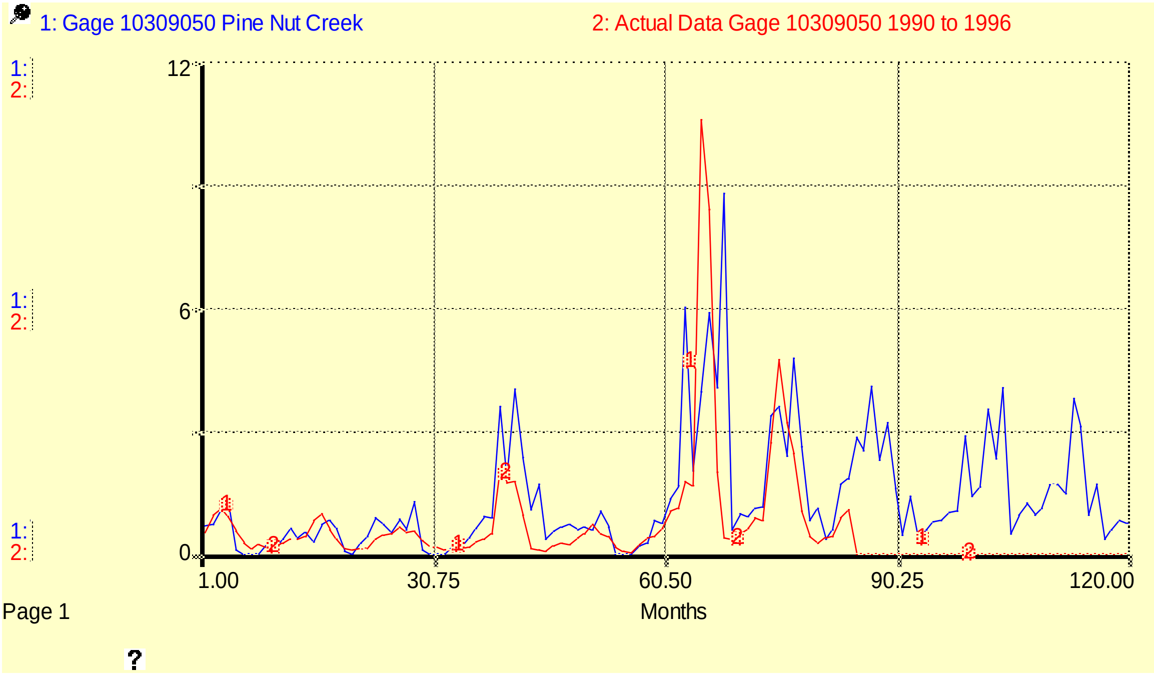


Figure 57. Pine Nut Creek 1990-1999 Simulation, Actual vs. Model

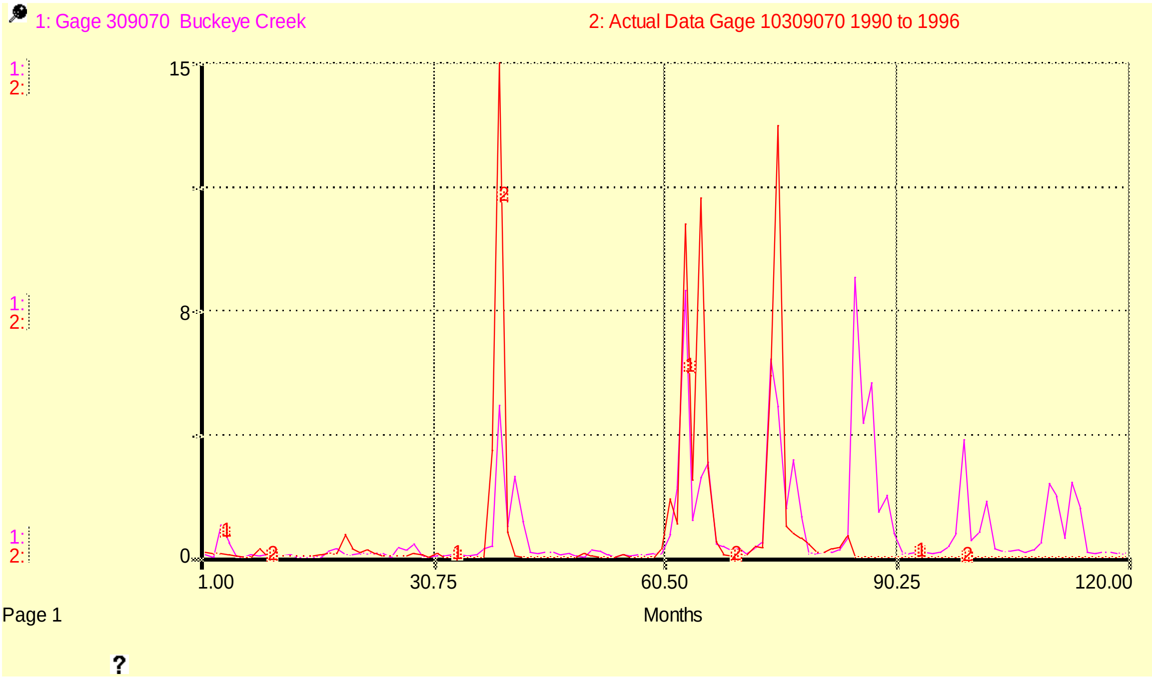


Figure 58. Buckeye Creek 1990-1999 Simulation, Actual vs. Model

The gages for Pine Nut Creek and Buckeye Creek are located a significant distance upstream from their entry points into the Allerman Canal. Thus, the amount of tributary surface flow that actually makes it to the valley floor does not mirror the surface flow at the upstream gage. Nonetheless, in the model, as with other tributaries, 100% of the gaged surface flow enters the valley. This was done to account for the likely significant subsurface component to the tributaries in question, and to account for the other subsurface flow coming off the mountains in the areas adjacent to the tributaries. Given the large amounts of groundwater that enter the valley from the mountains, having the tributaries carry 100% of their upstream gages may still under represent the system. Thus, keeping flow at 100% for the gaged tributaries, and not differentiating between ground and surface water flows, seems an appropriate way to represent tributary flow.

2.3.5 East Fork from Indian Creek to the Confluence: Gaged Inflows and Outflows

Indian Creek (Gage 10309035)

Shortly after supplying the Allerman Canal, the East Fork receives inflow from Indian Creek, a USGS gaged East Fork tributary with a year round period of record of only 1995-1997. The years 1994 and 1998 offer partial records of eight and nine months respectively. Indian Creek transports water from various upstream sources as well as its own headwaters. Because of the human element involved in many of these releases as well as the very limited amount of data, the decision was made to use regression relationships to correlate Indian Creek to East Fork Headwater flow, and build a larger data set (1984-2004) based on the relationships attained, however weak. That way, this inflow to the East Fork could be accounted for when later diversions, which typically hold the 1984-2004 period of record, are correlated to their respective adjacent flow in the river.

Regression analysis revealed surprisingly reasonable linear trend lines for all months spare May, where the mean was used instead of a flow formula. Where linear regression was used, R^2 values ranged from a low of 0.21 in June to a high of 0.99 in January. As with previous high January R^2 values, the R^2 value of 0.99 is not indicative of a perfect fit, but rather the result of the fact that the flood of 1997 made the data appear to fit very well. Results of the 1990-1999 simulation appear in Figure 59.

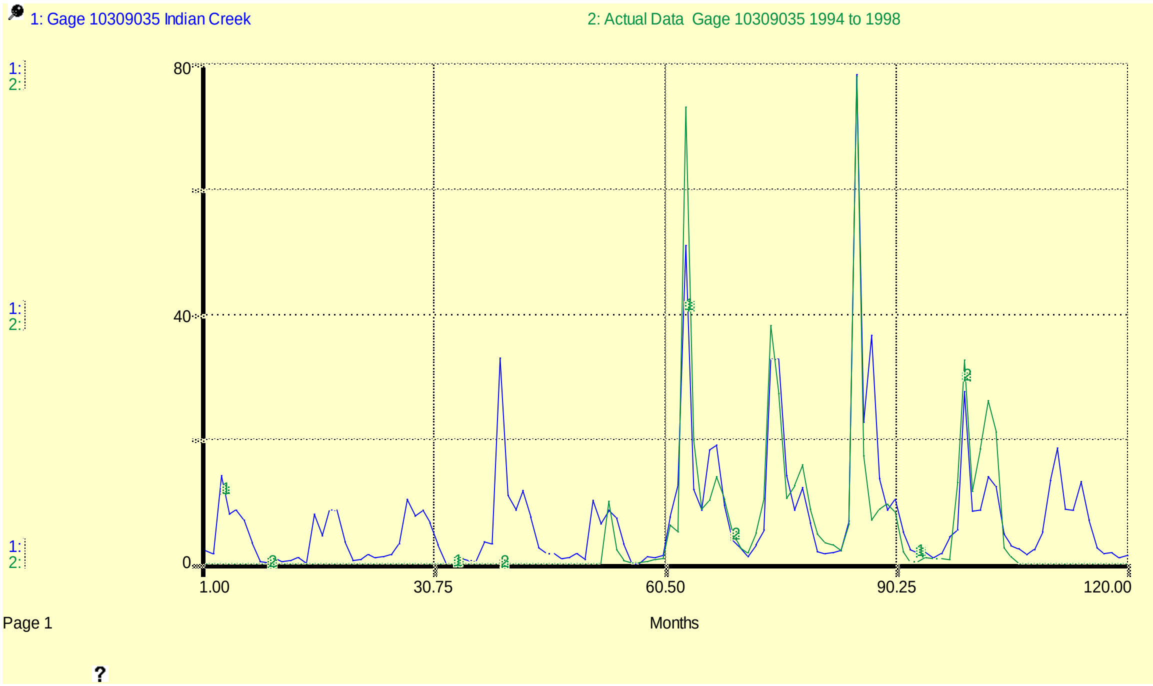


Figure 59. Gage 10308800 Indian Creek 1990-1999 Simulation, Actual vs. Model (Only 1994-1998 Actual Data Available)

Flow in Indian Creek is related to releases from two upstream reservoirs: Harvey Place Reservoir and Indian Creek Reservoir, with the latter being significantly larger. The timing of these releases is based on individual purchases and decisions that cannot be modeled. Because of these releases, Indian Creek acts more like a canal than a natural tributary. Given these facts, and the lack of an appreciable historical record, the above simulation is deemed a success. Obviously, it has its flaws, notably the under prediction of 1995. Overall, however, the modeled pattern of flow mimics the actual pattern somewhat consistently.

C83 Virginia Ditch

Approximately two miles downstream from Indian Creek, the East Fork encounters a series of diversions, the first of which is the Virginia Ditch, a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 11,833 acre-feet with a standard deviation of 3,002 acre-feet. The maximum total annual flow recorded at this gage is 17,428 acre-feet (1997). The minimum total annual flow recorded at this gage is 7,201 acre-feet (1990). Figure 60 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

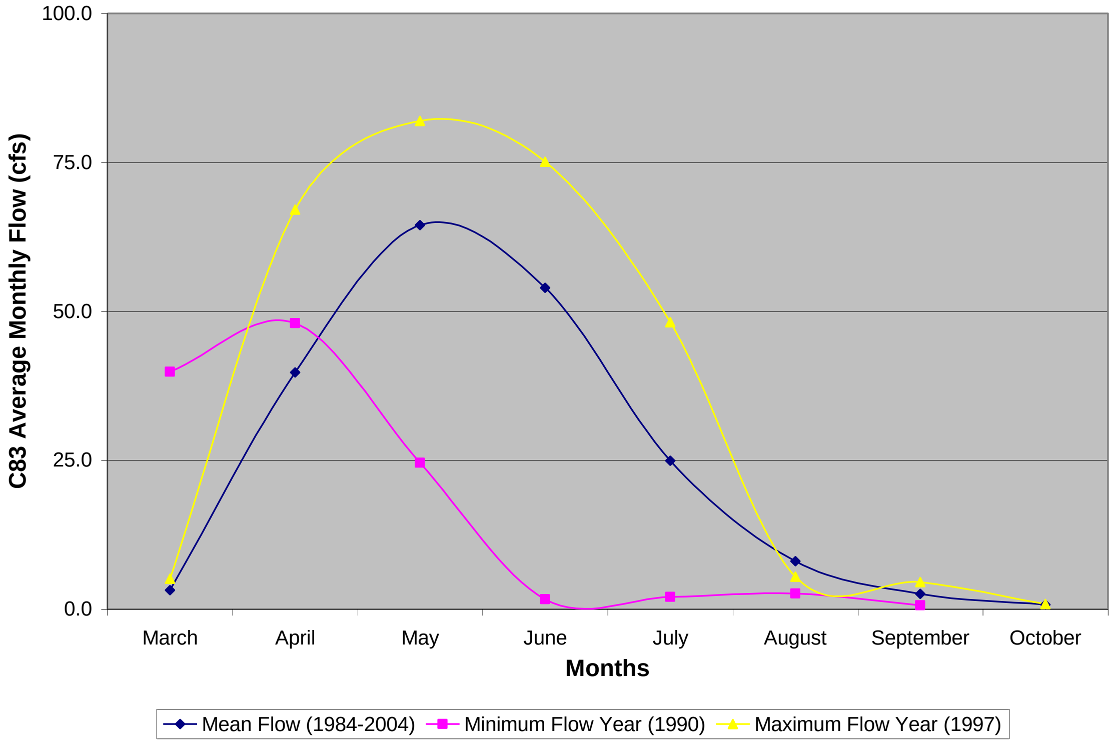


Figure 60. Mean, Minimum, and Maximum Annual Flows for C83 Virginia Ditch

Records at this ditch were kept from March through October, with March records sporadically recorded. Flow in this ditch was correlated to Gage 10309000 plus inflow from Indian Creek minus outflow to the Allerman Canal. Regression analysis revealed well correlated linear and natural log trend lines for June through August. There was no observable trend in March, April, or May so those months are defined by their mean. October's average flow was near zero. R^2 values ranged from a low of 0.12 for September to a high of 0.82 for July. Results of the 1990-1999 simulation appear in Figure 61.

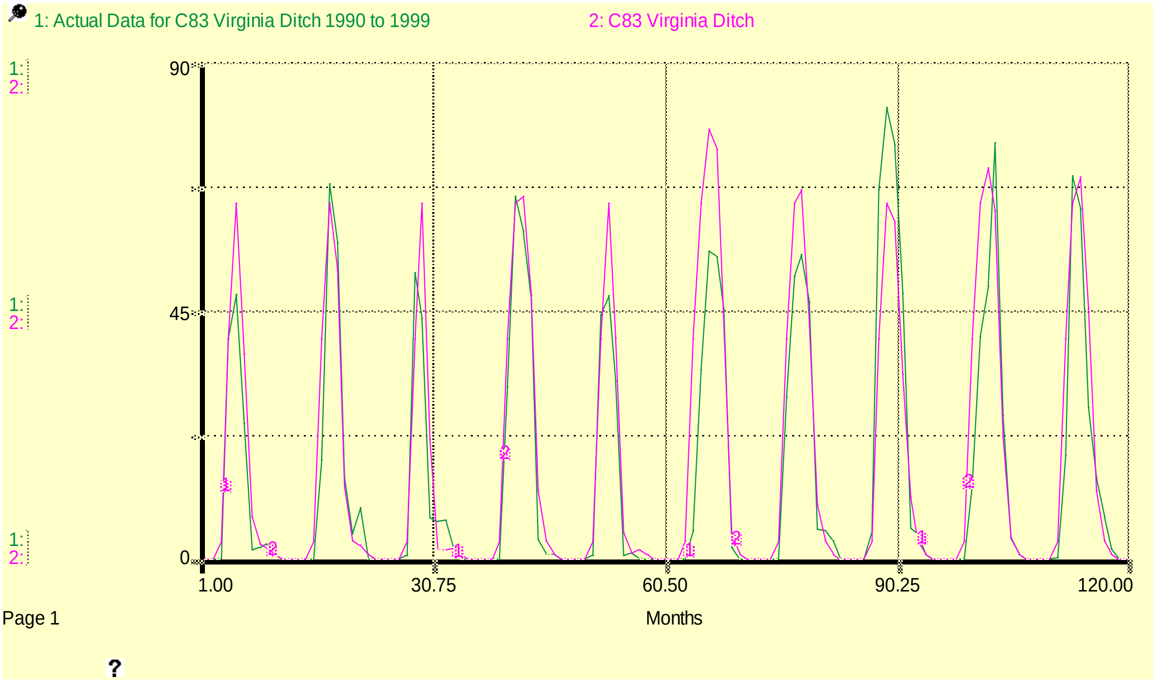


Figure 61. C83 Virginia Ditch 1990-1999 Simulation, Actual vs. Model

The model yields quality results with the exception of 1995 through 1997. Taking a closer look at the actual data from those years (see Appendix B) reveals a lot of scatter for the summer months. While there is a definable trend, there are some significant outliers, notably occurring in 1995-1997.

C84 Rocky Slough

Directly across from the Virginia Ditch on the East side of the Carson River is the Rocky Slough, a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 17,042 acre-feet with a standard deviation of 4,432 acre-feet. The maximum total annual flow recorded at this gage is 26,334 acre-feet (1986). The minimum total annual flow recorded at this gage is 11,749 acre-feet (1990). Figure 62 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

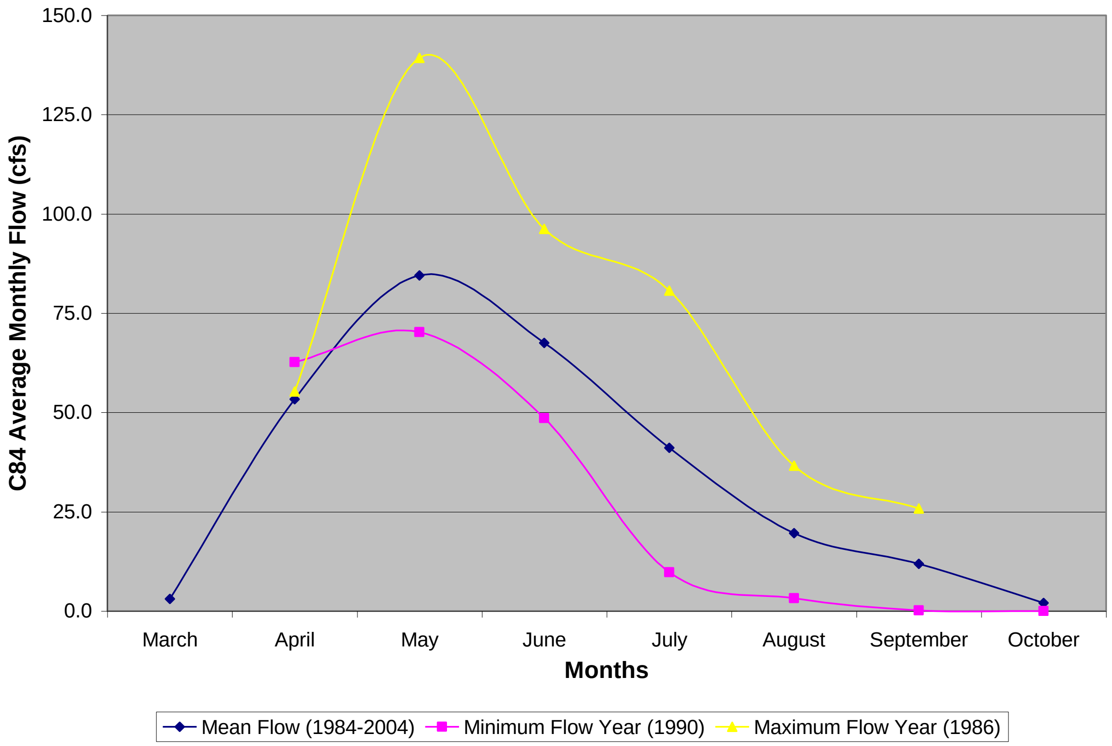


Figure 62. Mean, Minimum, and Maximum Annual Flows for C84 Rocky Slough

Records at this ditch were kept from March through October, with March records not kept prior to 1991. Flow in this ditch was correlated to the same data set as Virginia Ditch (Gage 10309000 plus inflow from Indian Creek minus outflow to the Allerman Canal), as the two diversions are directly across from each other. Regression analysis revealed well correlated linear and natural log trend lines for June through September. There was no observable trend in March, April, or May, or October so those months are defined by their mean. R^2 values ranged from a low of 0.47 for June to a high of 0.87 for July. Results of the 1990-1999 simulation appear in Figure 63.

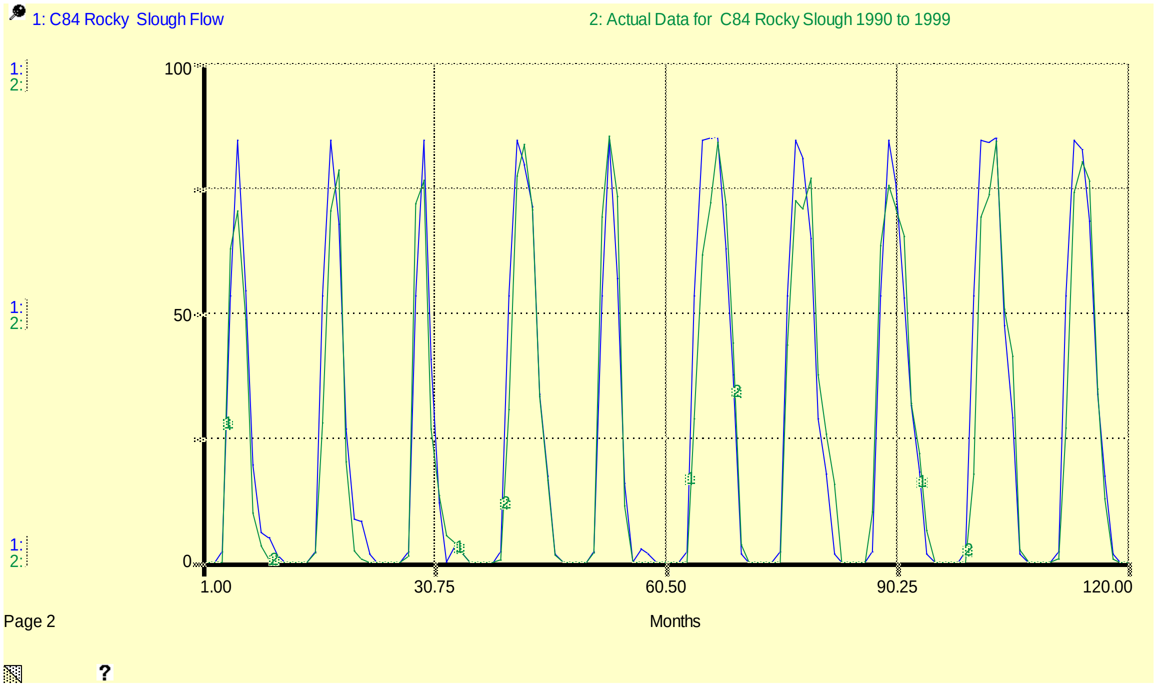


Figure 63. C84 Rocky Slough 1990-1999 Simulation, Actual vs. Model

The model yields very respectable results with the exception of some of the spring months, which are defined by the mean. Taking a closer look at the actual data for those months (see Appendix B) reveals that in the 1980s, some spring diversions were abnormally high. These high spring diversion years markedly increased the historical averages. Such outliers can skew a data set, and as such, modelers often remove them so as to have a more accurate model. However, this particular behavior cannot be definitively ruled out for the future, so in this case, the means were not adjusted.

C85 Edna Ditch

Shortly after the Rocky Slough's diversion on the East Fork, the Edna Ditch diverts water from the Rocky Slough to the southwest. The Edna Ditch is a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 5,407 acre-feet with a standard deviation of 1,886 acre-feet. The maximum total annual flow recorded at this gage is 8,149 acre-feet (1985). The minimum total annual flow recorded at this gage is 2,669 acre-feet (1992). It is interesting to note that despite the fact that the Edna Ditch diverts water directly from the Rocky Slough, neither the maximum nor minimum flow years of the two ditches coincide. Figure 64 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

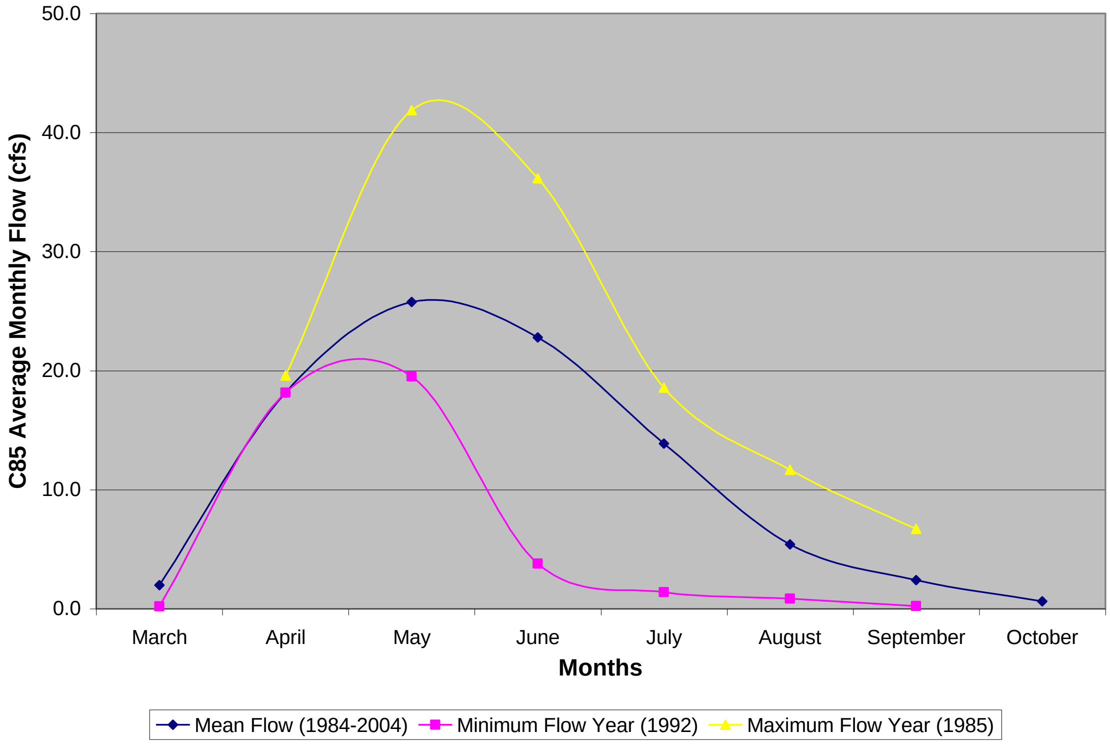


Figure 64. Mean, Minimum, and Maximum Annual Flows for C85 Edna Ditch

Records at this ditch were kept from March through October, with March records not kept prior to 1991. Flow in this ditch was correlated to Rocky Slough. Regression analysis revealed well correlated linear and natural log trend lines for April through September. R^2 values ranged from a low of 0.18 for March to a high of 0.79 for July. Results of the 1990-1999 simulation appear in Figure 65.

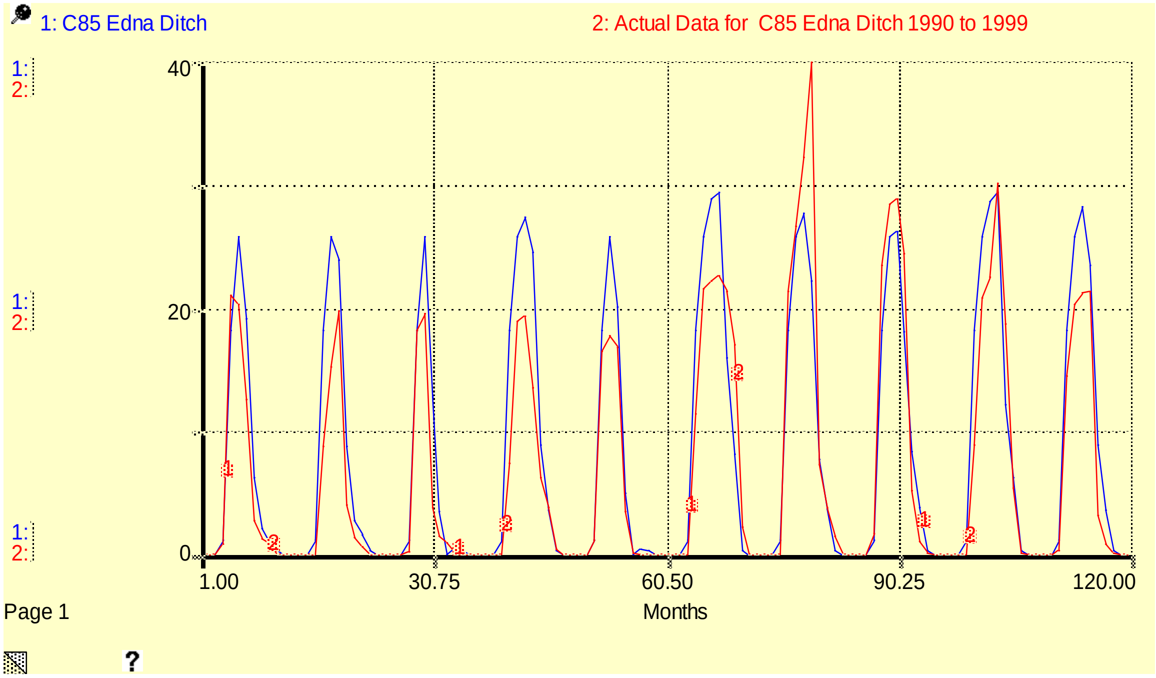


Figure 65. C85 Edna Ditch 1990-1999 Simulation, Actual vs. Model

The model yields respectable results, yet the Edna Ditch experiences the same issue as the Rocky Slough because the Rocky Slough is the source of the Edna Ditch. As with the Rocky Slough, the higher spring flow in the 1980s cannot be definitively ruled out to not occur in the future, thus the model's under prediction of Edna Ditch's spring flows for the 1990s remain a function of this behavior. The anomaly in 1996 appears to be either an inaccurate reading or the result of some unusual event.

C87 Cottonwood Slough

Shortly after the Virginia Ditch's diversion on the East Fork, the East Fork again diverts water easterly, this time into the Cottonwood Slough, a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 6,221 acre-feet with a standard deviation of 1,944 acre-feet. The maximum total annual flow recorded at this gage is 10,887 acre-feet (1986). The minimum total annual flow recorded at this gage is 3,525 acre-feet (2003). Figure 66 presents a graphical representation of this slough's mean and extreme annual flows in cfs.

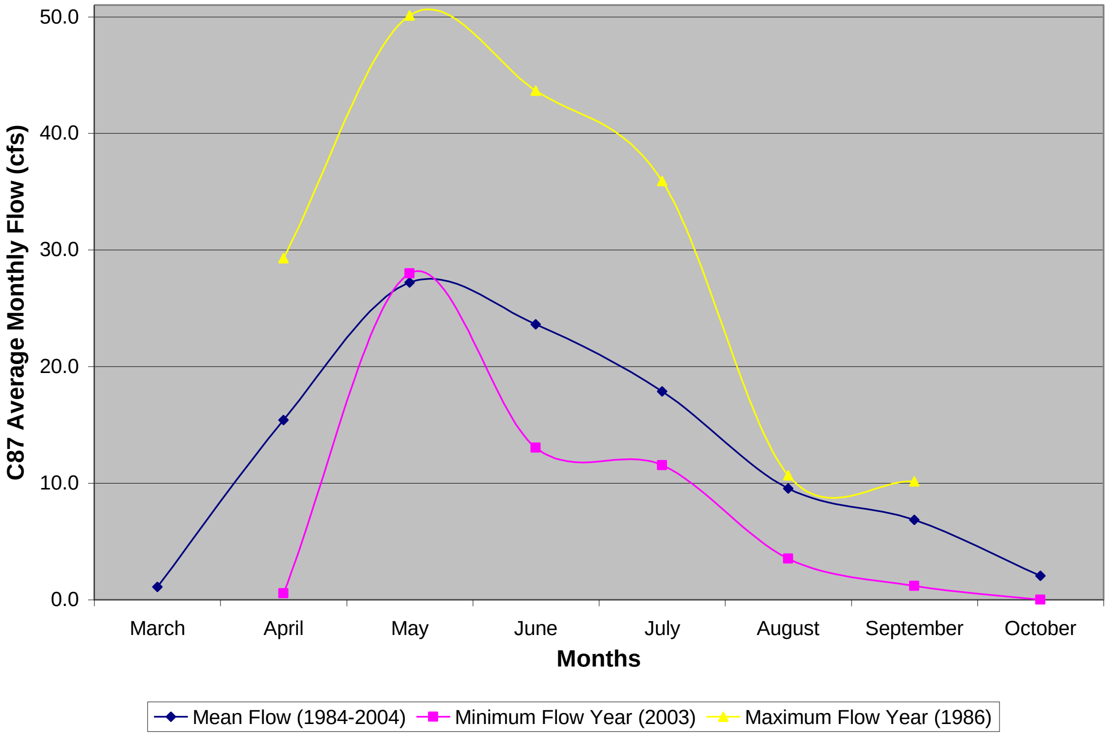


Figure 66. Mean, Minimum, and Maximum Annual Flows for C87 Cottonwood Slough

Records at this ditch were kept from March through October, with March records not kept prior to 1991. Flow in this ditch was correlated to Gage 10309000 plus inflow from Indian Creek minus outflow to the Allerman Canal, Virginia Ditch, and Rocky Slough. Data for this ditch is somewhat random. Regression analysis revealed uncorrelated linear and natural log trend lines for all months. As a result, mean monthly values were used to approximate flow for this ditch. Results of the 1990-1999 simulation appear in Figure 67.

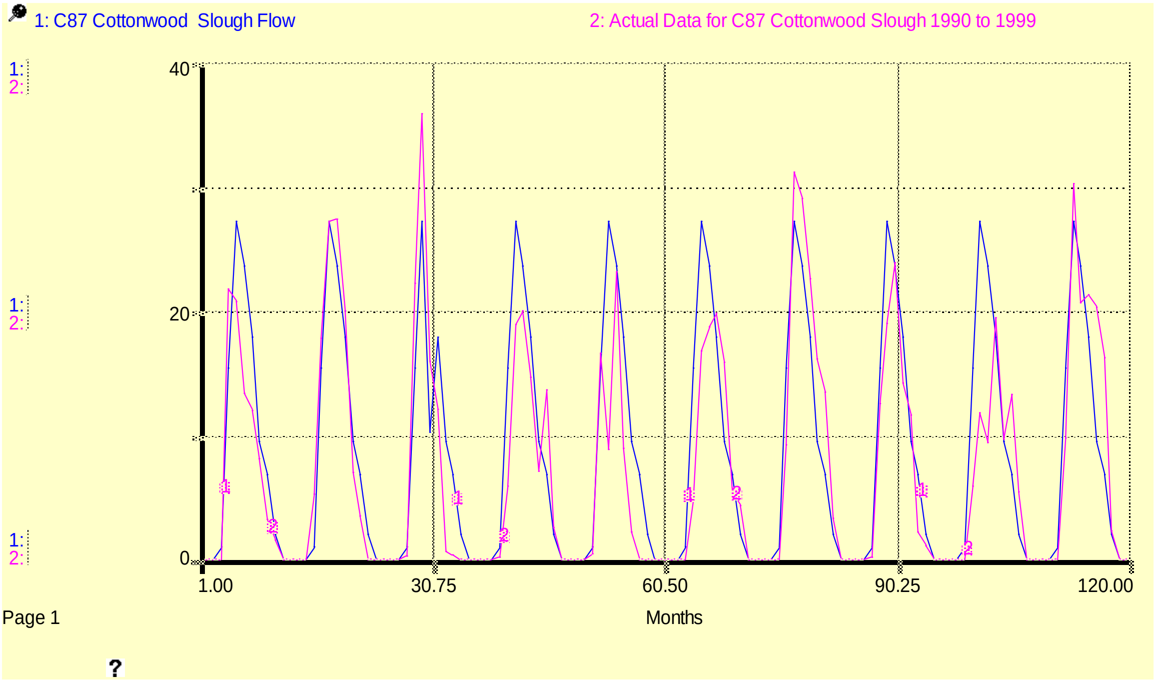


Figure 67. C87 Cottonwood Slough 1990-1999 Simulation, Actual vs. Model

As mentioned above, flow in this ditch is not consistent. Of particular interest is the high peak flow of 1993 and the low peak flow of 1998. While somewhat arbitrary in nature, the peak flows for the 1990s do have a limited range. The highest peak flow during the 1990s occurred in 1996 (36 cfs) and the lowest peak flow during this time period occurred in 1998 (20 cfs). Thus, using an average here, while not ideal, is reasonable nonetheless.

C88 Henningson Ditch

Directly across from the Cottonwood Slough is the Henningson Ditch, a Federal Water Master gaged diversion with a period of record of 1984-2004. Based on this record, the mean annual flow of this ditch is 4,860 acre-feet with a standard deviation of 1,290 acre-feet. The maximum total annual flow recorded at this gage is 7,117 acre-feet (1997). The minimum total annual flow recorded at this gage is 2,583 acre-feet (1994). Figure 68 presents a graphical representation of this ditch’s mean and extreme annual flows in cfs.

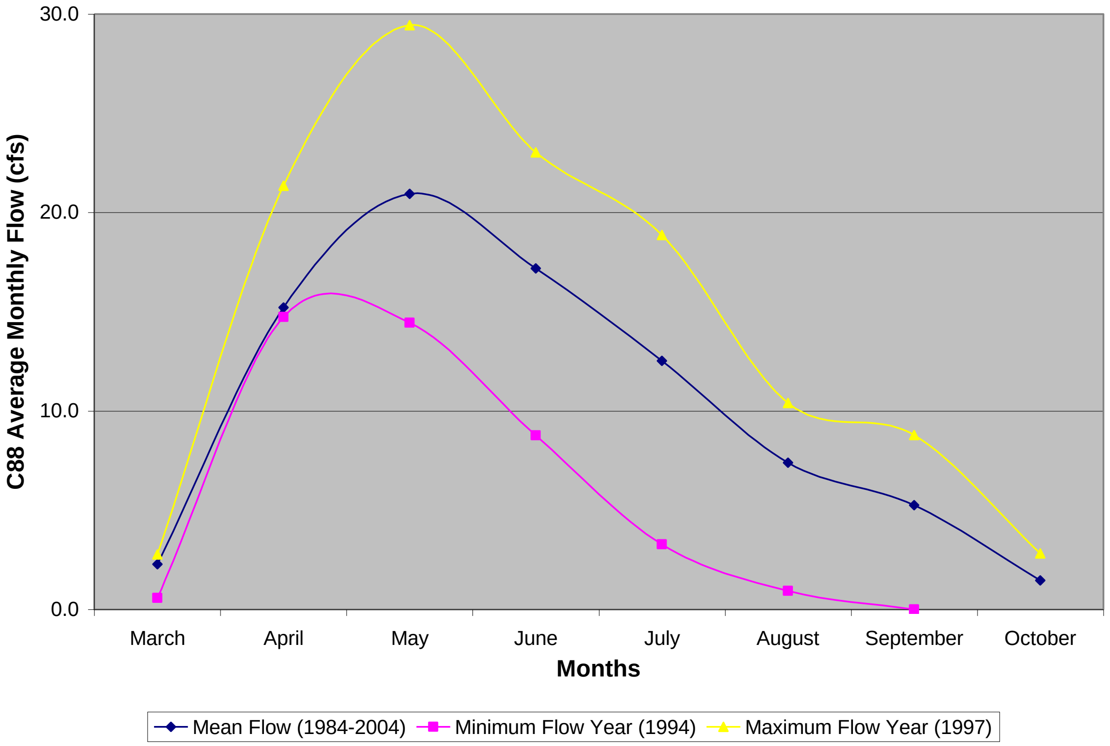


Figure 68. Mean, Minimum, and Maximum Annual Flows for C88 Henningson Ditch

Records at this ditch were kept from March through October, with March records not kept prior to 1991. As with the Cottonwood Slough above, flow in this ditch was correlated to Gage 10309000 plus inflow from Indian Creek minus outflow to the Allerman Canal, Virginia Ditch, and Rocky Slough. Regression analysis revealed fairly correlated linear and natural log trend lines for all months spare April and October. R^2 values ranged from a low of 0.14 for June to a high of 0.58 for July. Mean monthly values were used to approximate flow for April and October. Results of the 1990-1999 simulation appear in Figure 69.

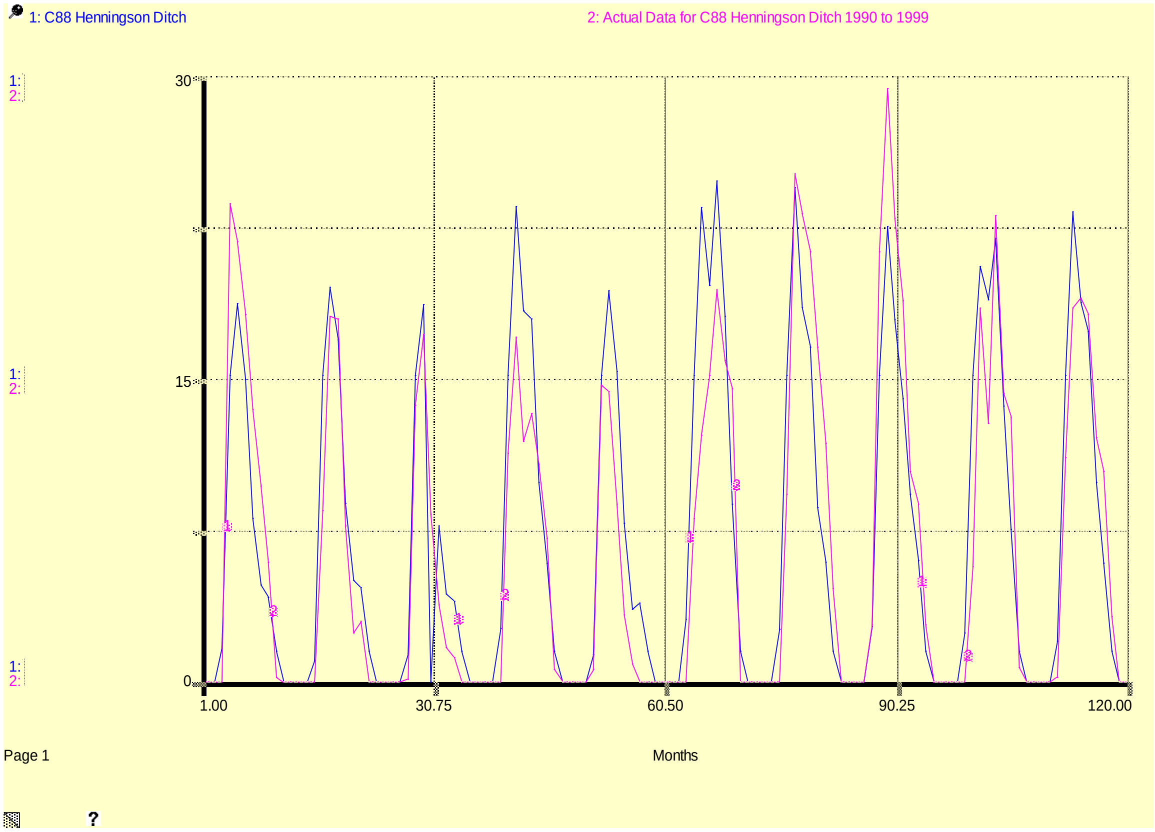


Figure 69. C88 Henningson Ditch 1990-1999 Simulation, Actual vs. Model

Given the mediocre trend lines, the model yields surprisingly respectable results. There are few areas where the model over and under predicts, however, the flow regime is for the most part identified, and given the scale, the fluctuations are relatively mild.

C89 Heyburn Ditch

The Heyburn Ditch is a Federal Water Master gaged diversion with a period of record of 1984-1985 and 1987-2004. Based on this record, the mean annual flow of this ditch is 6,807 acre-feet with a standard deviation of 2,143 acre-feet. The maximum total annual flow recorded at this gage is 10,701 acre-feet (1995). The minimum total annual flow recorded at this gage is 3,407 acre-feet (2001). Figure 70 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

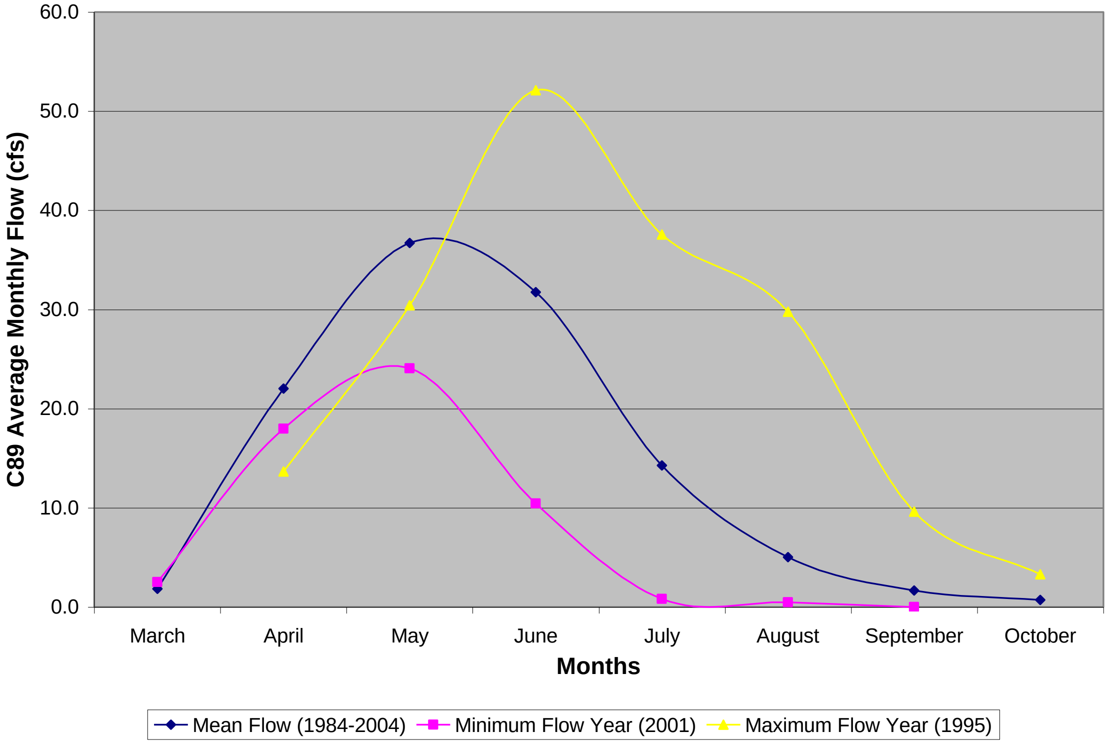


Figure 70. Mean, Minimum, and Maximum Annual Flows for C89 Heyburn Ditch

Records at this ditch were kept from March through October, with March records not kept prior to 1992 and October records not kept prior to 1995. This ditch’s source of flow is strictly return flows mostly from Virginia Ditch and Cottonwood Slough via Martin Slough (Figure 7). Some of the flow in the Heyburn Ditch likely originated from the Allerman Canal as well. The model supplies Heyburn Ditch through various combination of return flow from all of the above. Results of the 1990-1999 simulation appear in Figure 71.

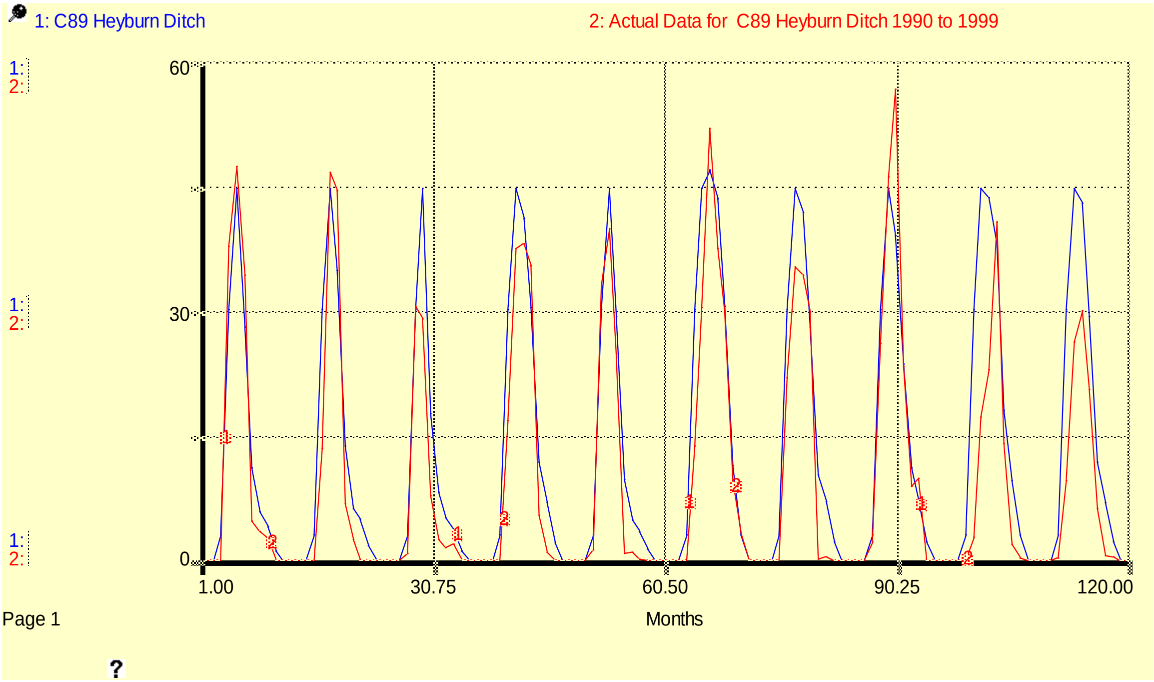


Figure 71. C88 Heyburn Ditch 1990-1999 Simulation, Actual vs. Model

The model correctly identifies the general flow regime of the ditch, however it misses the fluctuations. This is because flow in the Heyburn Ditch is based predominantly on return flow from both the Cottonwood Slough and the Virginia Ditch. Because of a lack of correlation to adjacent river flow, flow in the Virginia Ditch in March through May (when the peak flow typically occurs) is based on its historical monthly mean. Similarly, Cottonwood Slough's flow is entirely based on its historical monthly means. Thus, one would not expect a great deal of annual fluctuation for the modeled version of Heyburn Ditch. Flow towards the end of the summer is better predicted, as Virginia Ditch was able to be correlated to actual flow in the river during those months.

Ambrosetti Pond Outlet (Gage 10310448)

Ambrosetti Pond feeds into the main Carson River as the river heads northeast out of Carson Valley toward Dayton. It is discussed in this chapter because it is fed by return flows from East Fork ditches, namely the William Slough, Middle Ditch, East Ditch, and Heyburn Ditch. The USGS gage at the Ambrosetti Pond outlet has a sporadic period of record of 1992-2004 with only the years 1994-96 and 2001-2003 consisting of twelve month data sets. Luckily, the full six year data set is somewhat representative in that it includes wet, drought and normal precipitation years. Based on this brief six year record, the mean annual flow of this ditch is 8,871 acre-feet with a standard deviation of 4,230 acre-feet. The maximum total annual flow recorded at this gage is 16,037 acre-feet (1996). The minimum total annual flow recorded at this gage is 5,317 acre-feet (1994). Figure 72 presents a graphical representation of this gage's mean and extreme annual flows in cfs.

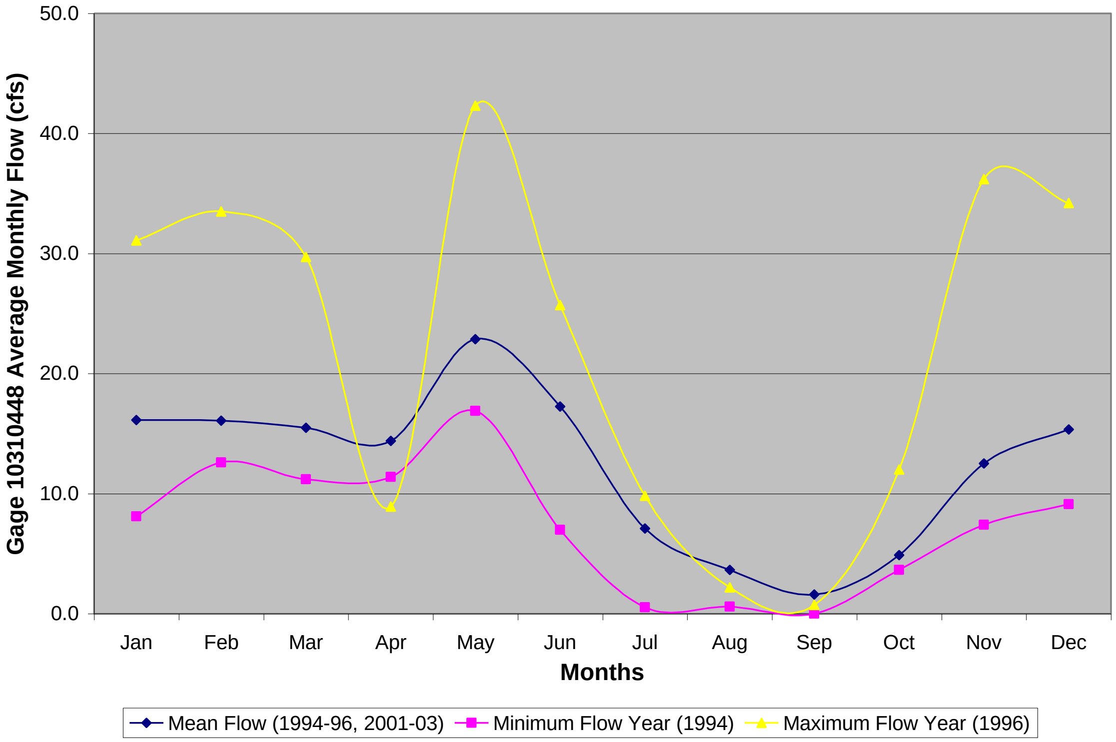


Figure 72. Mean, Minimum, and Maximum Annual Flows for the Outlet at Ambrosetti Pond (Gage 10310448)

In the model, return flows from the various ditches that supply Ambrosetti Pond are governed such that they supply the pond with flow at appropriate times. Because of the limited data set, average flows are used to govern the releases from Ambrosetti Pond. Outflow is subject to adequate amounts of inflow to the pond, so drought conditions are reflected in the model's depiction of the pond and outflow to the Carson River.

Major Ungaged Ditches and Sloughs in the East Fork

As in the West Fork and Brockliss Slough regions, there are many significant ungaged ditches in the East Fork region that can trace some or all of their flow from the East Fork. Table 9 summarizes these ditches.

Table 9. Estimated Capacity Flow of Major Ungaged East Fork Ditches and Sloughs (J. Larrouy, personal communication, 2005)

Ditch/Slough Name	Estimated Capacity Flow (cfs) prior to the River Going on Regulation
Homestream Slough	25
Williams Slough	25
St. Louis Straight	20
Martin Slough	18
Middle Ditch	15
Poleline Ditch	15
East Ditch	10

Flow derivation for the St. Louis Straight, Homestream Slough, and Williams Slough uses the same methodology as the West Fork ungaged diversions, as explained in Section 6.1.4. The remaining ditches are governed by the receipt of various percentages of return flows from upstream ditches.

2.3.6 Modeling the Main Carson River

East of Genoa, the East Fork and the historic West Fork converge and form the Main Carson River. A mile and a half downstream, the Brockliss Slough enters the Carson River, and the river turns to the northeast. As the river makes its way toward Dayton, tributary inflow and diversion outflow is limited. In Dayton Valley, large scale irrigation resumes as the river supplies nine gaged diversions prior to entering Lahontan Reservoir in Churchill Valley. In this part of the Carson River, all of the diversion gages are monitored by the Federal Water Master, and diversion records are only maintained for April through September. There is likely some minor occasional flow occurring in March and even less in October. However, because that flow is minimal and cannot be quantified, flows for March and October months in the model are defined as zero.

Main Carson River Tributary Inflow

Clear Creek

Clear Creek enters the Main Carson River approximately five miles after the Brockliss Slough rejoins the river. Clear Creek is a USGS gaged tributary to the Main Carson River with a year round period of record of 1949-1961 and 1990-2003. Based on this record, the mean annual flow of this creek is 4,127 acre-feet with a standard deviation of 2,153 acre-feet. The maximum total annual flow recorded at this gage is 9,383 acre-feet (1997). The minimum total annual flow recorded at this gage is 1,543 acre-feet (1992). Figure presents a graphical representation of this creek's mean and extreme annual flows in cfs.

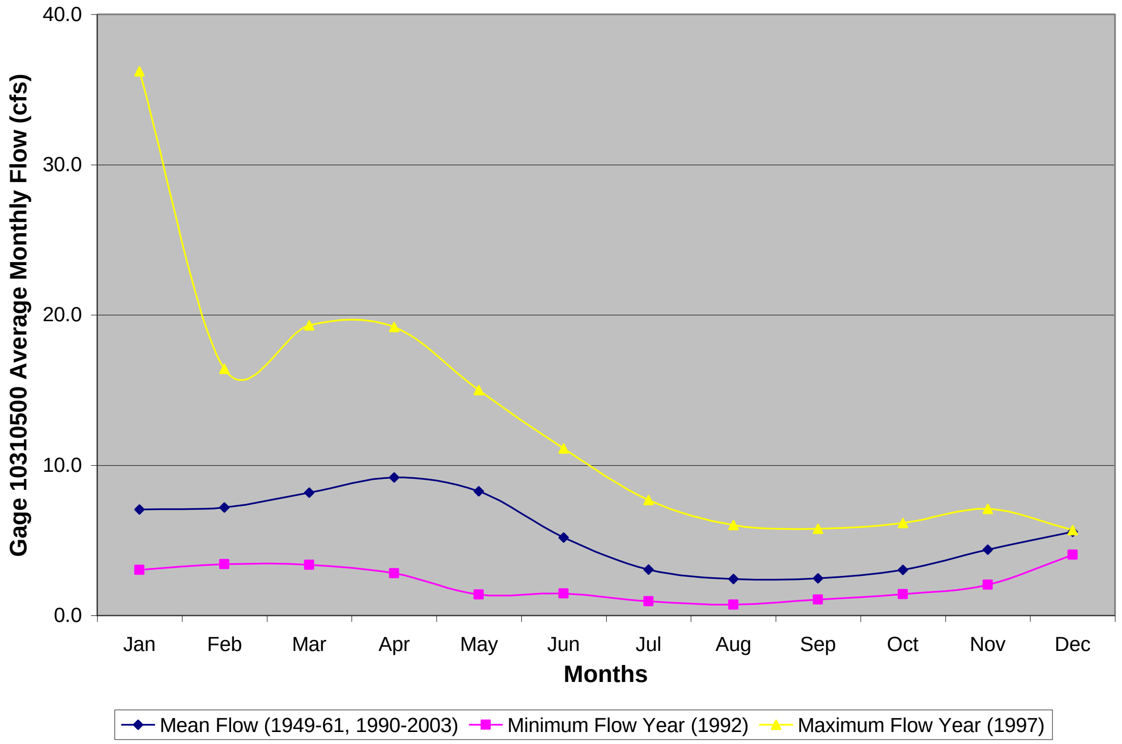


Figure 73. Mean, Minimum, and Maximum Annual Flows for Clear Creek (Gage 10310500)

Flow in this creek was correlated to flow on the East Fork at Gage 10309000 because of the similarity in elevation (both are approximately 5,000 feet). Regression analysis revealed well correlated linear and natural log trend lines for all months, with R^2 values ranging from a low of 0.49 in September to a high of 0.91 in January. Results of the 1990-1999 simulation appear in Figure 74.

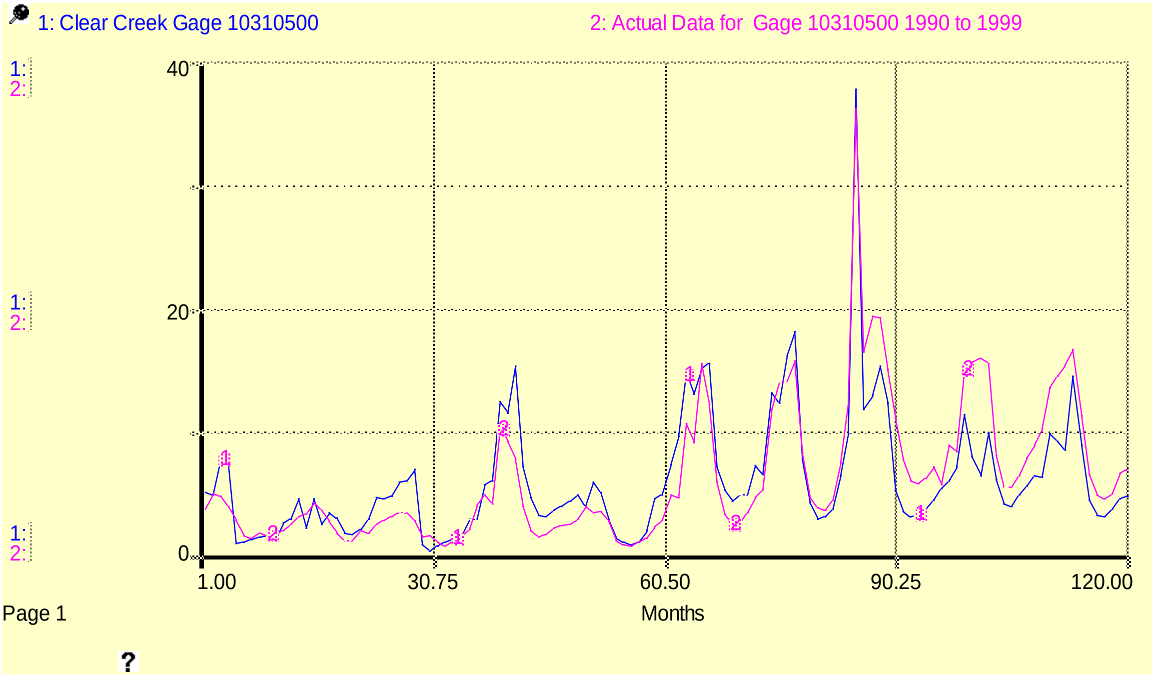


Figure 74. Clear Creek 1990-1999 Simulation, Actual vs. Model

Given the well correlated trend lines, the above results are not the quality expected. The model does follow the trends quite well, yet the springs of 1998 and 1999 are markedly off. Looking at the actual data (Appendix C) for those years reveals the issue. The trend line for April is fairly well correlated (R^2 = 0.59). Yet when the data for that month is graphed, the data points for 1998 and 1999 stand out as clear outliers. In fact, when they are removed, the R^2 jumps up to 0.69. Thus, the trend is correct. The "problem" is that this data set, like any real world data set, exhibits anomalies that cannot be modeled without vastly increasing the level of detail to the model. As mentioned earlier in different sections, it is not the goal of this model to predict such anomalies.

Kings Canyon Creek, Ash Canyon Creek, and Vicee Canyon Creek

These small, USGS gaged creeks flow off of the Sierras and into Eagle Valley west of Carson City. Collective mean annual flows for these three creeks is approximately 4000 acre-feet (Appendix C). These streams terminate some five miles west of the Carson River. In between is Carson City, where considerable groundwater pumping occurs. Some of the groundwater from these streams does likely make its way to Eagle Valley Creek, another gaged tributary that does feed into the Carson River. Given these circumstances, the three aforementioned streams are not deemed to have any significant impact on the Carson River and as such, are not included in the model. Rather, only flow from Eagle Valley Creek is included in the model.

Eagle Valley Creek

Eagle Valley Creek is a USGS gaged tributary to the Carson River that enters the river approximately seven miles after Clear Creek. Eagle Valley Creek has a year round period of record of 1949-1961 and 1990-2003. Based on this record, the mean annual flow of this creek is 2,449 acre-feet with a standard deviation of 2,984 acre-feet. The maximum total annual flow recorded at this gage is 9,383 acre-feet (1997). The minimum total annual flow recorded at this gage is 1,543 acre-feet (1992). Figure 75 presents a graphical representation of this creek's mean and extreme annual flows in cfs.

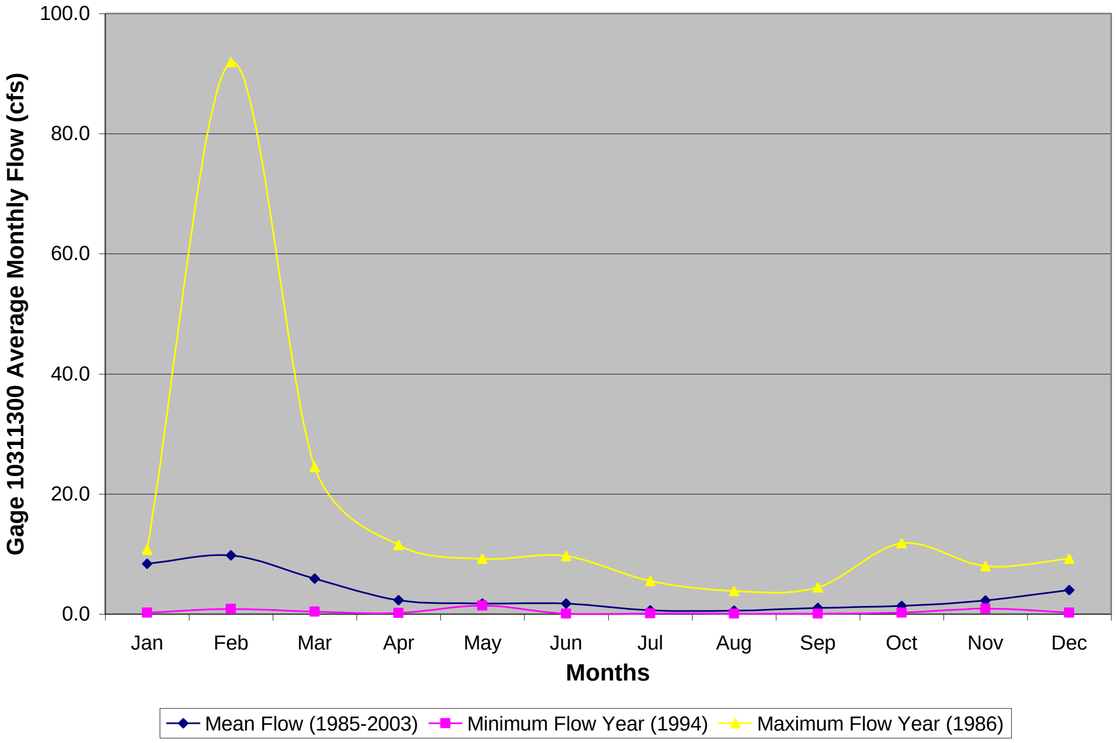


Figure 75. Mean, Minimum, and Maximum Annual Flows for Eagle Valley Creek (Gage 10311300)

Flow in this creek was also correlated to flow on the East Fork at Gage 10309000 because of the similarity in elevation (both are approximately 5,000 feet). Regression analysis revealed poorly correlated linear trend lines for most months, with R^2 values ranging from a low of 0.12 in June to a high of 0.97 in January (due to flood) . Results of the 1990-1999 simulation appear in Figure 76.

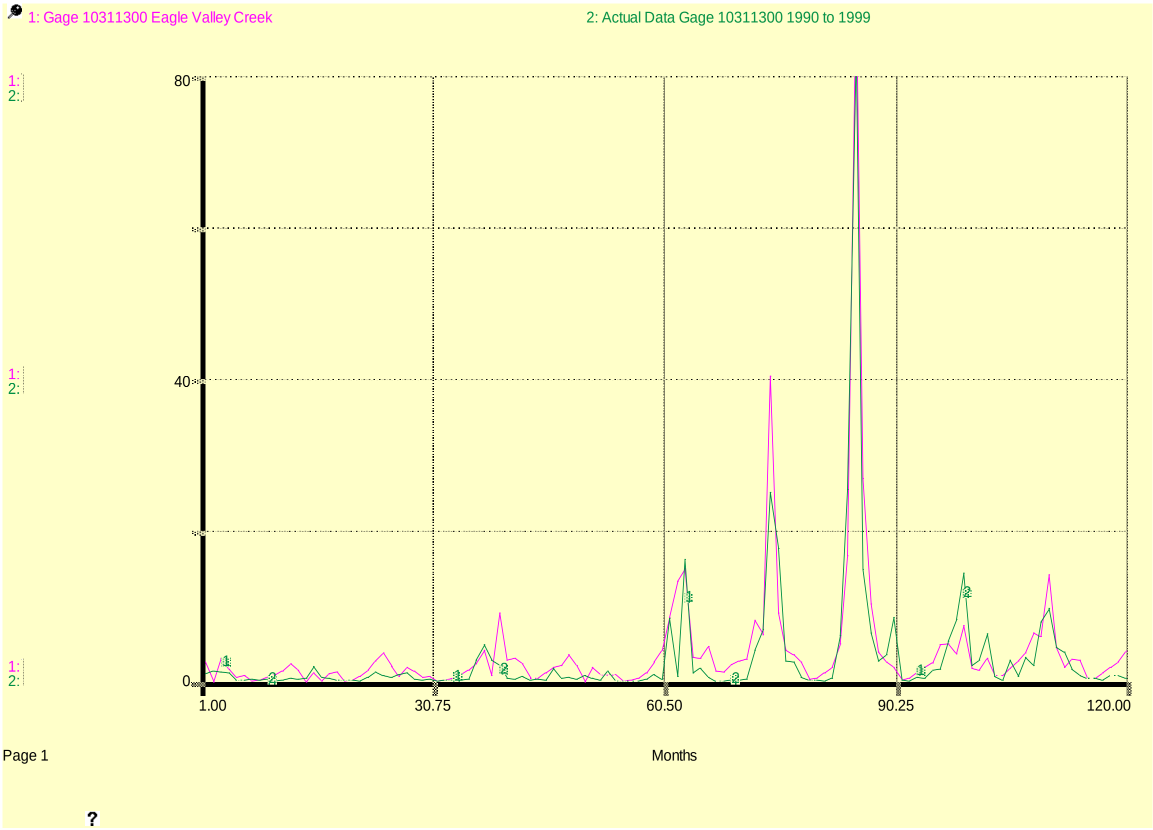


Figure 76. Eagle Valley Creek 1990-1999 Simulation, Actual vs. Model

Given the weakly correlated trend lines, the above results are expected. The model does follow the overall trends fairly well, and does successfully predict the flood of 1997 and the low flows as well. Because of the unique runoff curve of this creek (flow peaks in February vs. the typical May), and the relatively minimal flow that it typically contributes to the system, the above results are deemed adequate for inclusion in the model

Main Carson River Diversions: Mexican Ditch and Dayton Valley Ditches

C61 Mexican Ditch

A few miles after Clear Creek enters the Carson River, the river turns north where it feeds its last diversion, the Mexican Ditch, before heading northeast toward Dayton Valley. The Mexican Ditch has a period of record of 1989-2004. Based on this record, the mean annual flow of this ditch is 6,556 acre-feet with a standard deviation of 2,759 acre-feet. The maximum total annual flow recorded at this gage is 12,144 acre-feet (1999). The minimum total annual flow recorded at this gage is 2,349 acre-feet (2001).

Figure 77 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

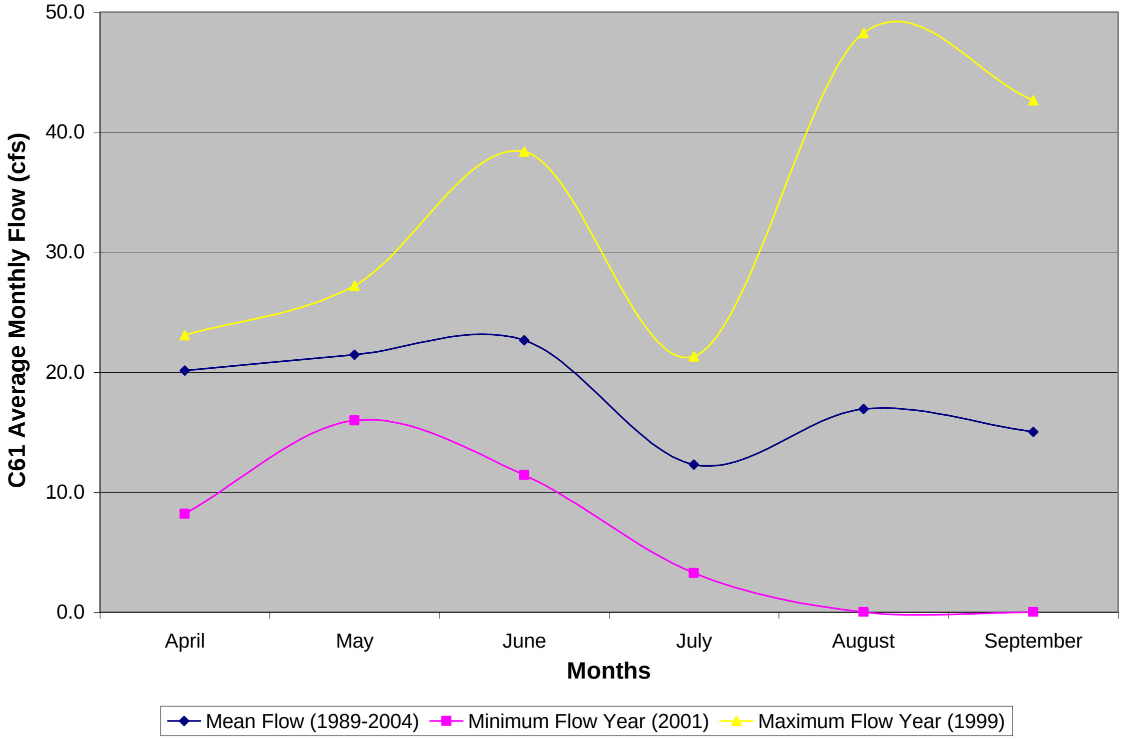


Figure 77. Mean, Minimum, and Maximum Annual Flows for C61 Mexican Ditch

Flow in this ditch was correlated to Gage 10311000, which is located just prior to the Mexican Ditch. Regression analysis revealed well correlated natural log trend lines for July through August. There was no observable trend in April, May, or June so those months are defined by their mean. This pattern is typical of the subsequent Dayton Valley diversions as well. R^2 values ranged from a low of 0.35 for July to a high of 0.77 for September. Results of the 1990-1999 simulation appear in Figure 78.

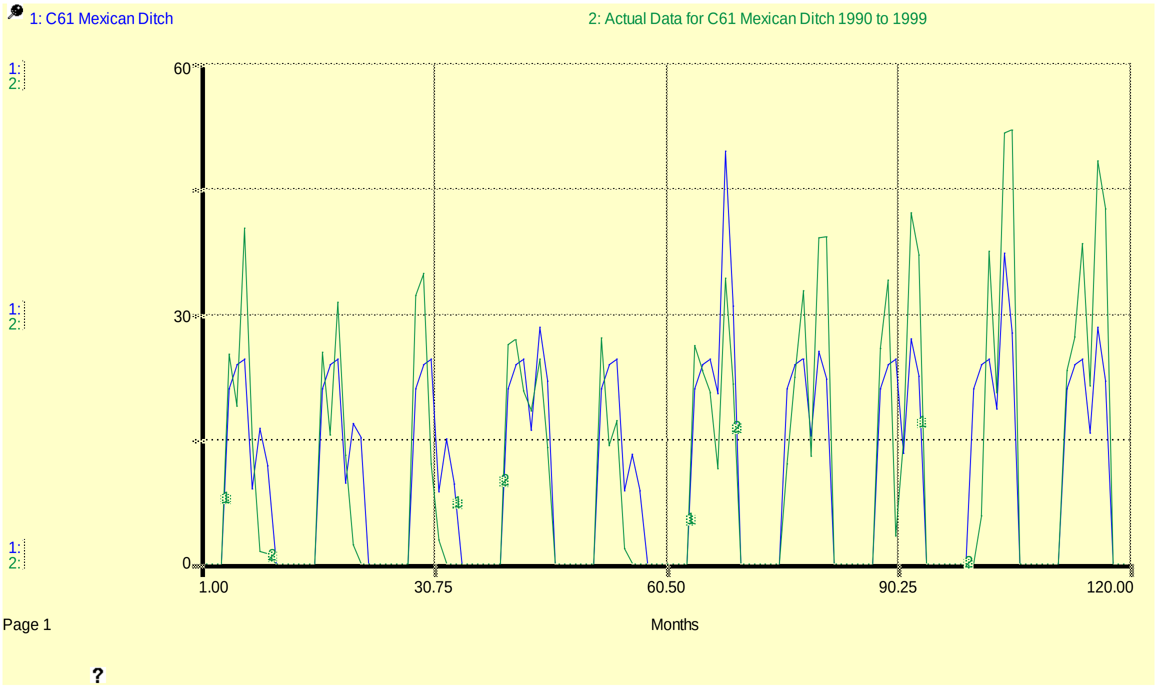


Figure 78. C61 Mexican Ditch 1990-1999 Simulation, Actual vs. Model

Given the close proximity of the most recent river gage, a more accurate portrayal may have been expected. However, the trend lines for the latter part of the summer reveal considerable scatter. The model does correctly identify the typical decrease in flow in July, however, the subsequent increase in August flow is consistently under predicted, as is the sustained higher flow during September. Taking a closer look at the actual data for the ditch (Appendix C) reveals the likely culprit for this under prediction is significant scatter for the summer months. While there is a definable trend, there are a few outliers, the notable ones occurring in 1995-1997.

C62 Rose Ditch

After the Mexican Ditch, the Carson River turns northeast toward Dayton Valley and receives inflow from Eagle Valley Creek. After the creek, the river passes USGS Gage 10311400 at Deer Run. Subsequent diversions are based on flow at this gage. The first such diversion encountered is the Rose Ditch, which has an historical record of 1984-2003. There was no diversion for agriculture in 2004. Based on this record, the mean annual flow of this ditch is 1,343 acre-feet with a standard deviation of 461 acre-feet. The maximum total annual flow recorded at this gage is 2,326 acre-feet (1984). The minimum total annual flow recorded at this gage is 321 acre-feet (2003). Figure 79 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

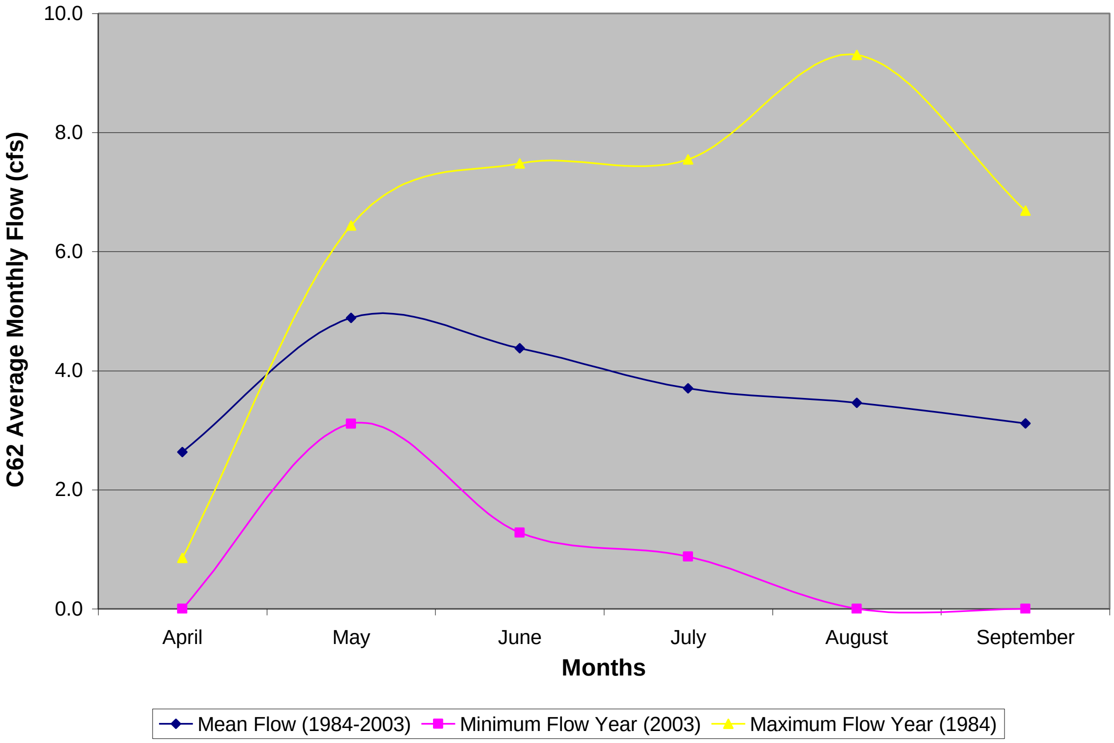


Figure 79. Mean, Minimum, and Maximum Annual Flows for C62 Rose Ditch

Flow in this ditch was correlated to Gage 10311400, which is located some six miles upstream. There was no observable trend in April through July, so those months are defined by their mean. Regression analysis for August and September resulted in some observable trends. R^2 values ranged from a low of 0.51 for August to a high of 0.65 for September. Results of the 1990-1999 simulation appear in Figure 80.

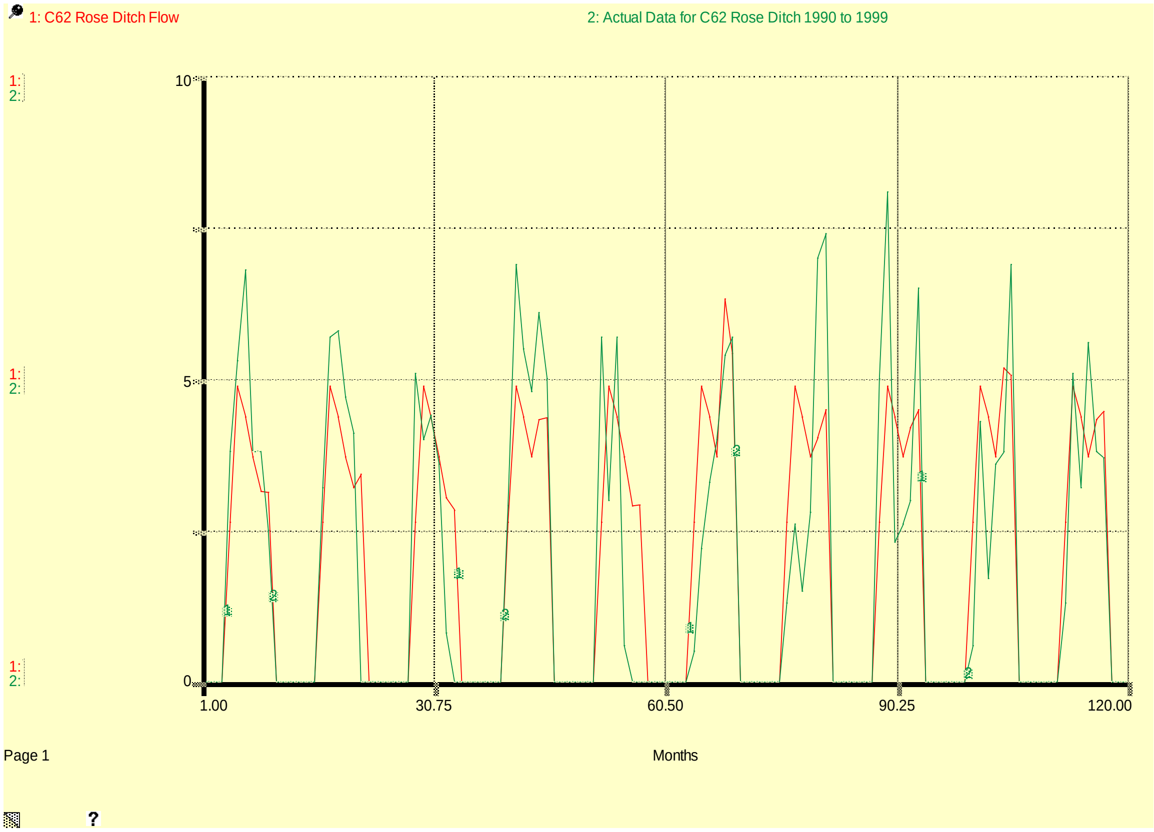


Figure 80. C62 Rose Ditch 1990-1999 Simulation, Actual vs. Model

Given the lack of uniformity in annual flow regimes, the above simulation results are considered a success. Where the model does vary (August and September), the model predicted flows fairly well.

C64 Fish Ditch

After the Rose Ditch, the Carson River historically supplied C63 Randall Ditch. However, the Randall Ditch has not been in use since 1989 and as such, it is not included in the model. The Fish Ditch, then, is the next diversion. The Fish Ditch has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 1,355 acre-feet with a standard deviation of 472 acre-feet. The maximum total annual flow recorded at this gage is 2,193 acre-feet (1995). The minimum total annual flow recorded at this gage is 520 acre-feet (2001). Figure 81 presents a graphical representation of this ditch’s mean and extreme annual flows in cfs.

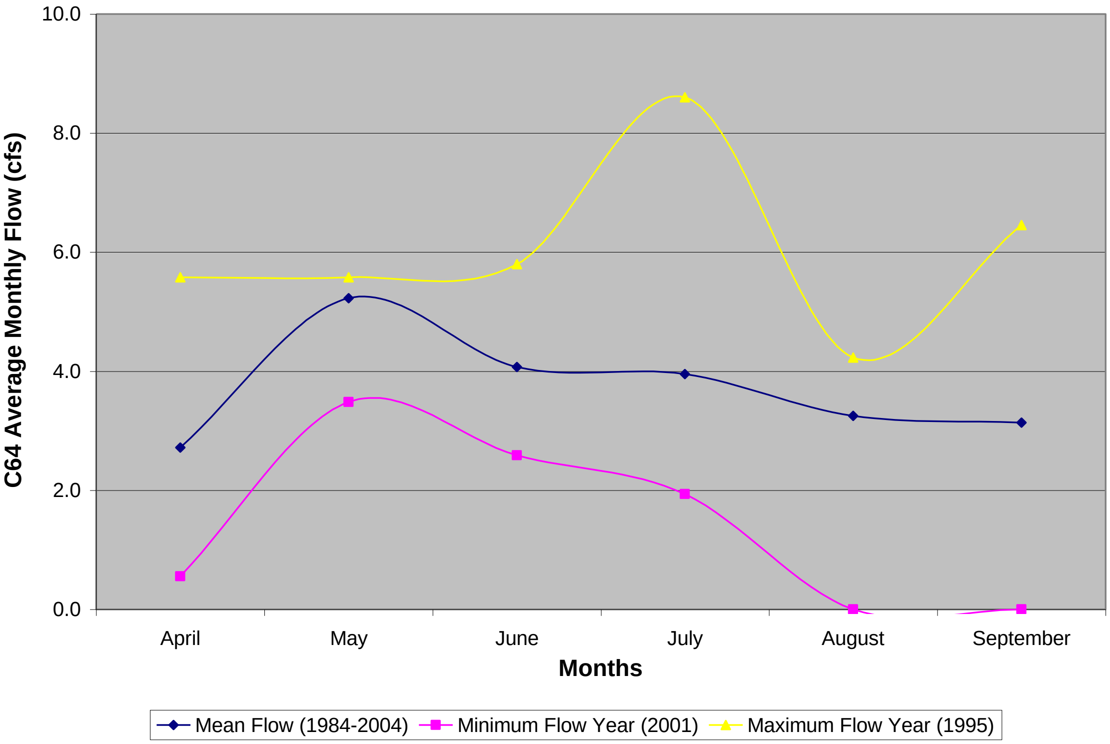


Figure 81. Mean, Minimum, and Maximum Annual Flows for C64 Fish Ditch

Flow in this ditch was correlated to Gage 10311400 minus the Rose Ditch. There was no observable trend in April through June, so those months are defined by their mean. Regression analysis for July through September resulted in some observable trends. R^2 values ranged from a low of 0.12 for July to a high of 0.46 for September. Results of the 1990-1999 simulation are shown in Figure 82.

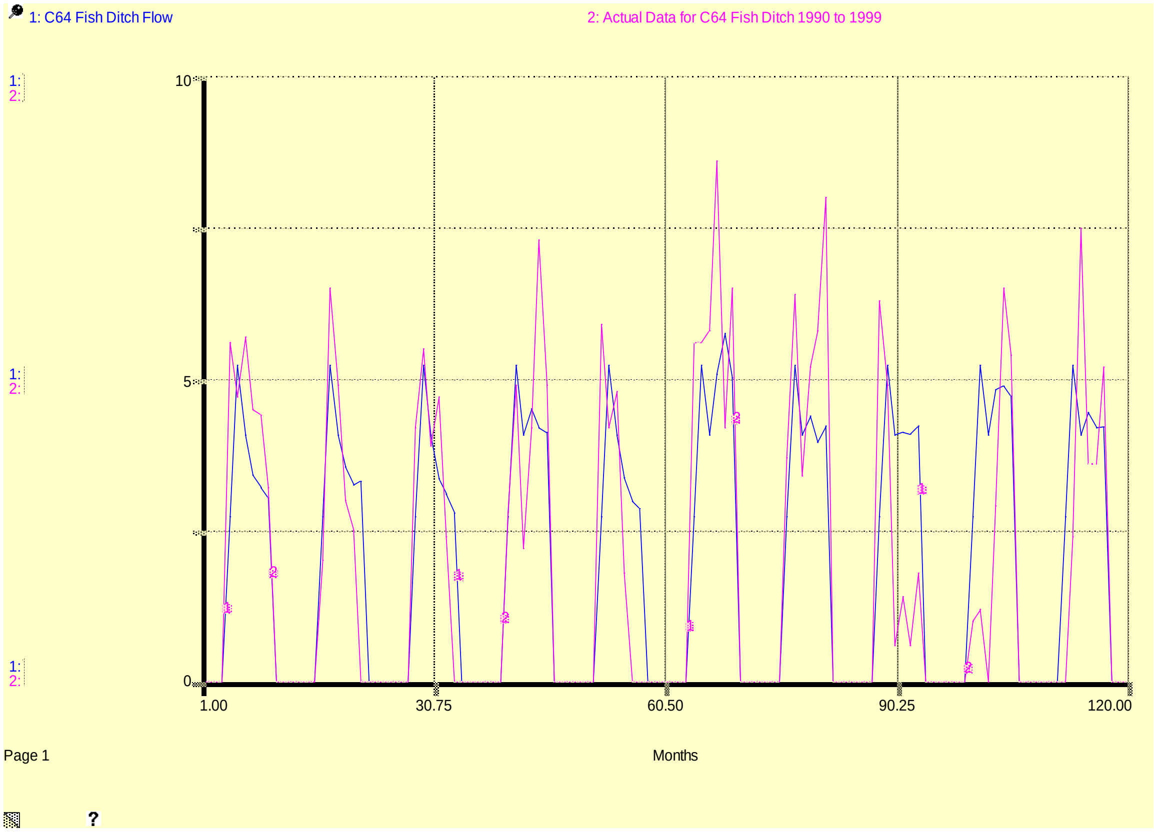


Figure 82. C64 Fish Ditch 1990-1999 Simulation, Actual vs. Model

As with the Rose Ditch, there is a significant lack of uniformity in annual flow regimes for the Fish Ditch that is difficult to predict. Notably, the model misses the very low flows of late summer 1997 and spring of 1998. Both of these incidents appear to be unrelated to flow in the river.

C65 Baroni Ditch

After the Fish Ditch, the Carson River next supplies the Baroni Ditch, which has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 2,330 acre-feet with a standard deviation of 699 acre-feet. The maximum total annual flow recorded at this gage is 3,909 acre-feet (1993). The minimum total annual flow recorded at this gage is 1,228 acre-feet (2001). Figure 83 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

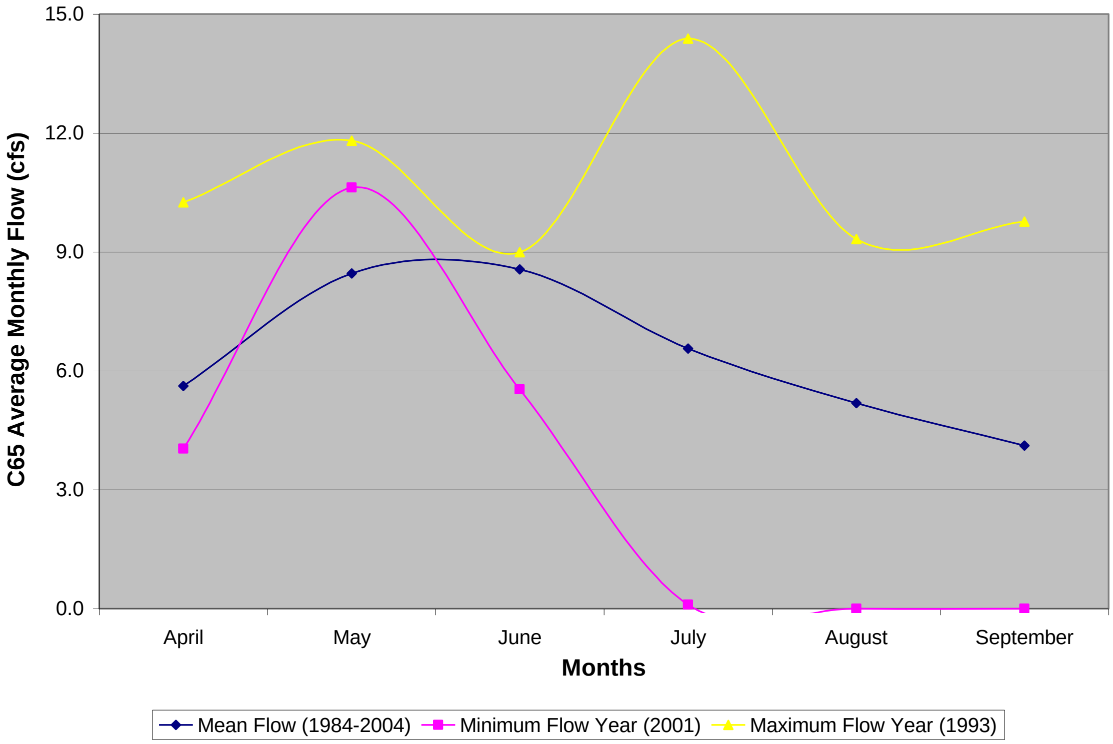


Figure 83. Mean, Minimum, and Maximum Annual Flows for C65 Baroni Ditch

Flow in this ditch was correlated to Gage 10311400 minus the Rose and Fish Ditches. There was no observable trend in April through June, so those months are defined by their mean. Regression analysis for July through September resulted in some observable trends. R^2 values ranged from a low of 0.32 for September to a high of 0.56 for August. Results of the 1990-1999 simulation appear in Figure 84.

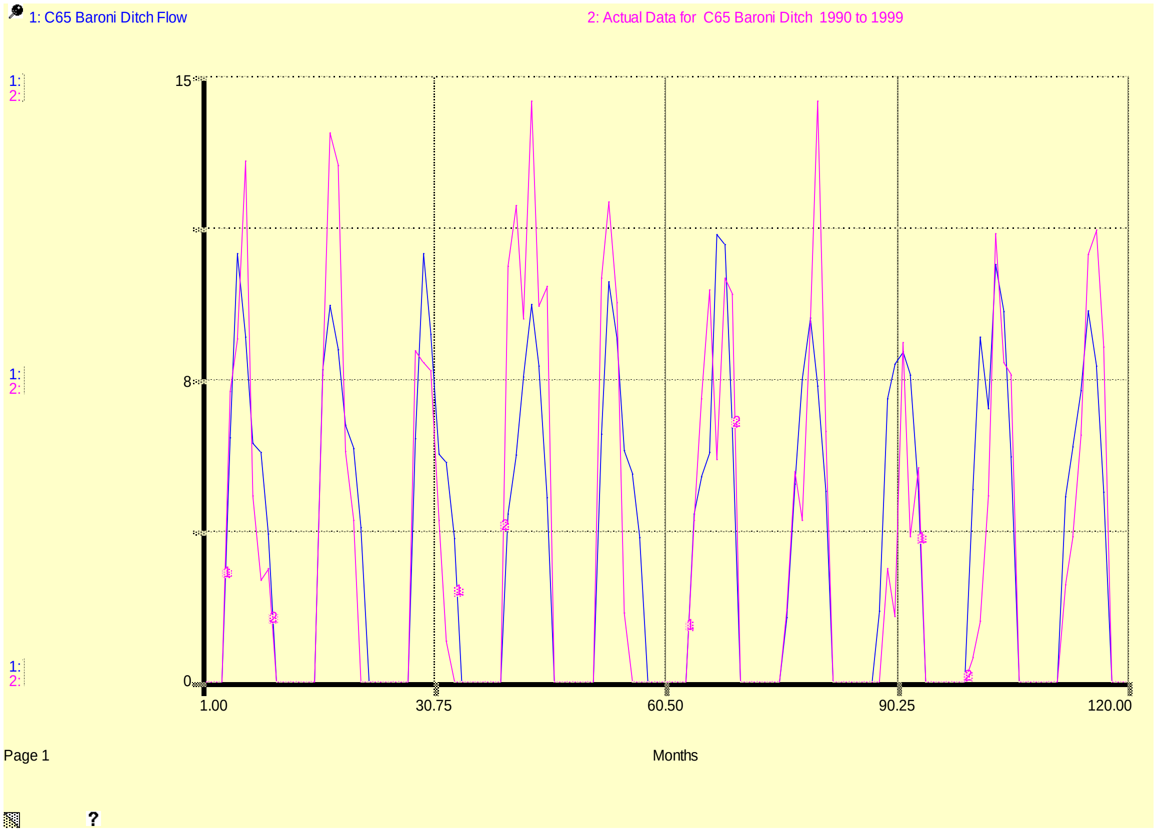


Figure 84. C65 Baroni Ditch 1990-1999 Simulation, Actual vs. Model

While the results are not spectacular, this ditch appears to be slightly more correlated to flow in the river than the previous two ditches. Like those ditches, though, flow in the Baroni Ditch does vary considerably, and thus is equally difficult to predict. The model misses some of the more extreme peak flows such as 1991, 1993 and 1996. As these years are all drought to normal precipitation years, these incidents appear to be unrelated to flow in the river.

C66 Cardelli Ditch

After the Baroni Ditch, the Carson River passes through USGS Gage 10311700 and then supplies the Cardelli Ditch, which has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 5,988 acre-feet with a standard deviation of 1,758 acre-feet. The maximum total annual flow recorded at this gage is 9,095 acre-feet (1993). The minimum total annual flow recorded at this gage is 3,380 acre-feet (2004). Figure 85 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

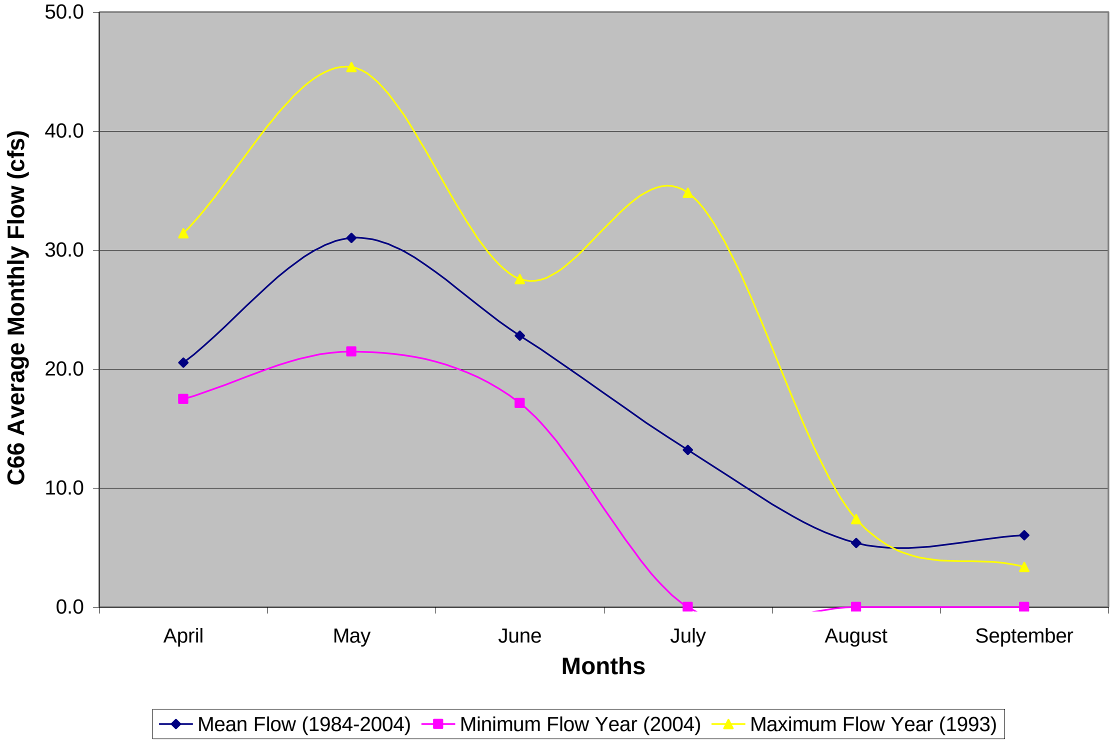


Figure 85. Mean, Minimum, and Maximum Annual Flows for C66 Cardelli Ditch

Flow in this ditch was correlated to Gage 10311700. There was no observable trend in April through June, so those months are defined by their mean. Regression analysis for July through September resulted in some observable trends. R^2 values ranged from a low of 0.38 for August to a high of 0.68 for July. Results of the 1990-1999 simulation appear in Figure 86.

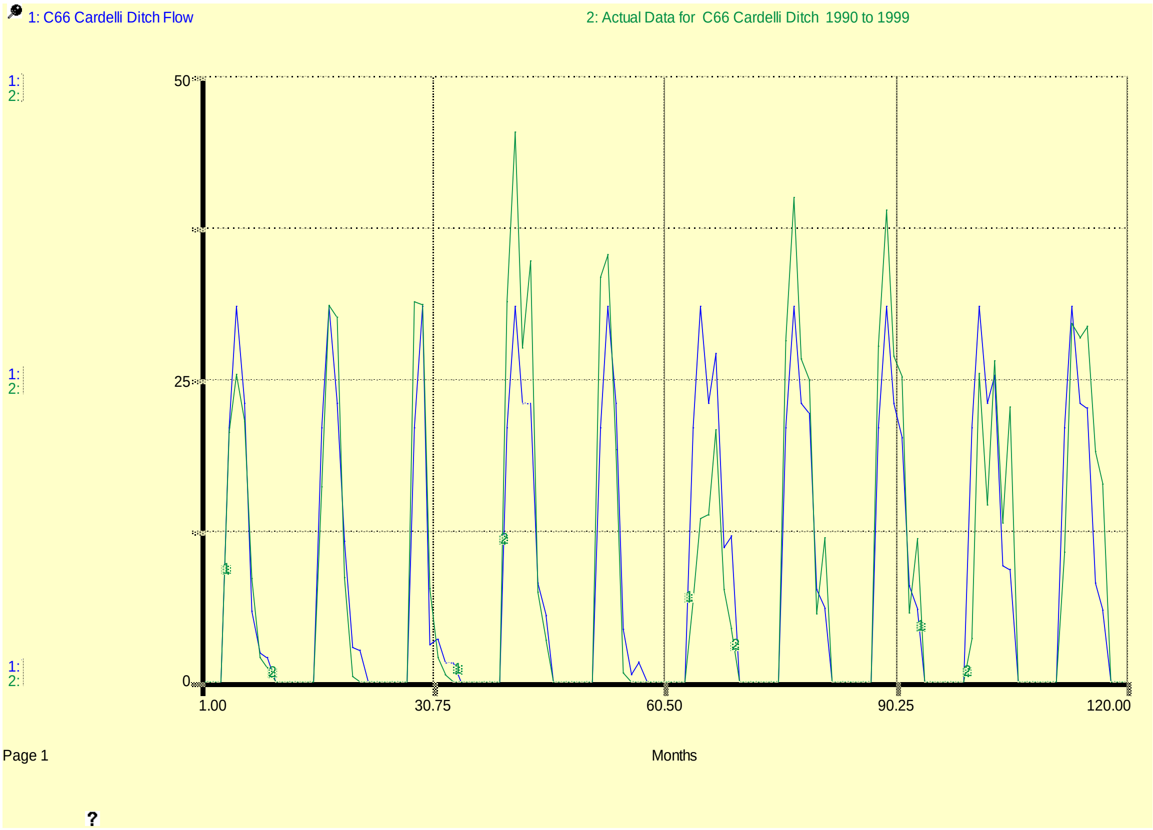


Figure 86. C66 Cardelli Ditch 1990-1999 Simulation, Actual vs. Model

Flow in the Cardelli Ditch is relatively consistent from year to year, with exception to the 1993, 1996, and 1997 high spring flows. Obviously the model misses these flows because it uses the mean to define spring flow diversion, however, the model does have success predicting the summer months.

C67 Quilici Ditch

After the Baroni Ditch, the Carson River supplies the Quilici Ditch, which has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 2,113 acre-feet with a standard deviation of 875 acre-feet. The maximum total annual flow recorded at this gage is 3,242 acre-feet (1999). The minimum total annual flow recorded at this gage is 535 acre-feet (1992). Figure 87 presents a graphical representation of this ditch’s mean and extreme annual flows in cfs.

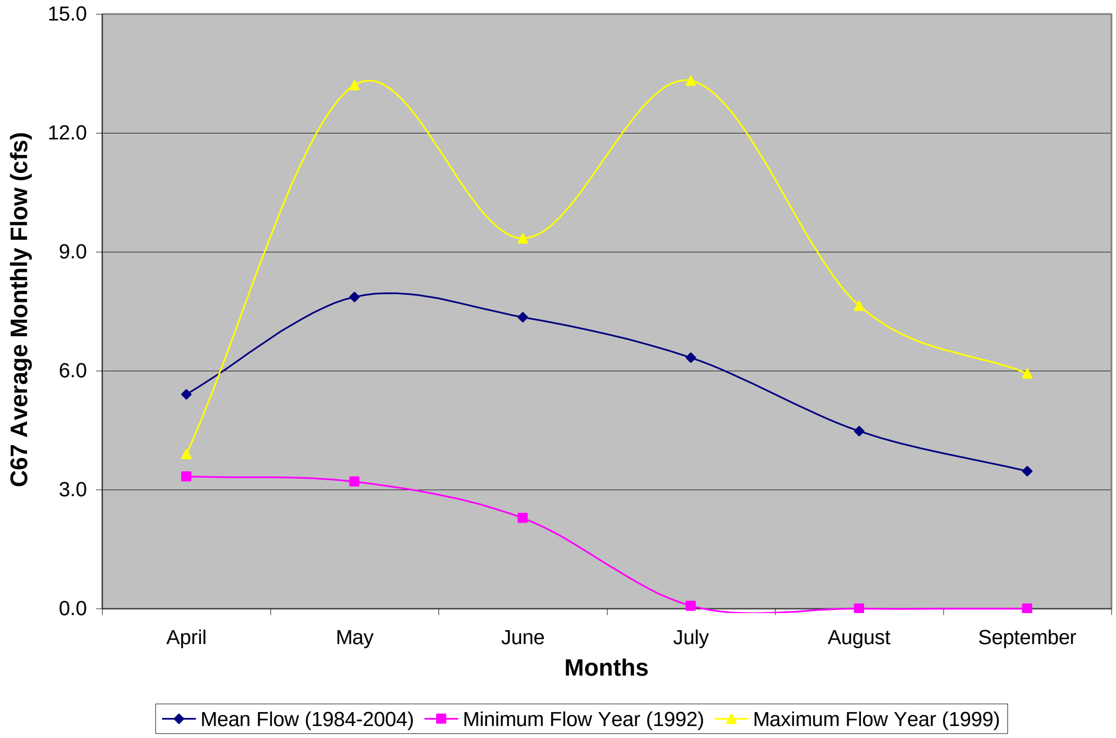


Figure 87. Mean, Minimum, and Maximum Annual Flows for C67 Quilici Ditch

Flow in this ditch was correlated to Gage 10311700 minus the Cardelli Ditch. There was no observable trend in April and June, so those months are defined by their mean. Regression analysis for May and July through September resulted in some observable trends. R^2 values ranged from a low of 0.08 for May to a high of 0.84 for July. Despite the very low R^2 value for May, the trend was visible and expected, and 8% is better than the alternative of using the mean (0%). Results of the 1990-1999 simulation appear in Figure 88.

Figure 88. C67 Quilici Ditch 1990-1999 Simulation, Actual vs. Model

Flow in the Quilici Ditch is much less in the early nineties (drought years) than in the mid-late nineties (wet years). The model does a fair job tracking the months not governed by the mean, however, the model shows diversions in the late summer of 1991, 1992 and 1995 when there is no flow at the gage. In these circumstances, it is possible that the ditch received its water from return flows after the gage, and thus there was no reason for the farmers to divert from the river. If this were the case, the model may have been correct in predicting flow in the ditch, but incorrect in identifying the source of that flow.

C68 Gee Ditch

After the Quilici Ditch, the Carson River supplies the Gee Ditch, which has an historical record of 1985-2004. Based on this record, the mean annual flow of this ditch is 1,111 acre-feet with a standard deviation of 653 acre-feet. The maximum total annual flow recorded at this gage is 2,943 acre-feet (1997). The minimum total annual flow recorded at this gage is 217 acre-feet (1986). Figure 89 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

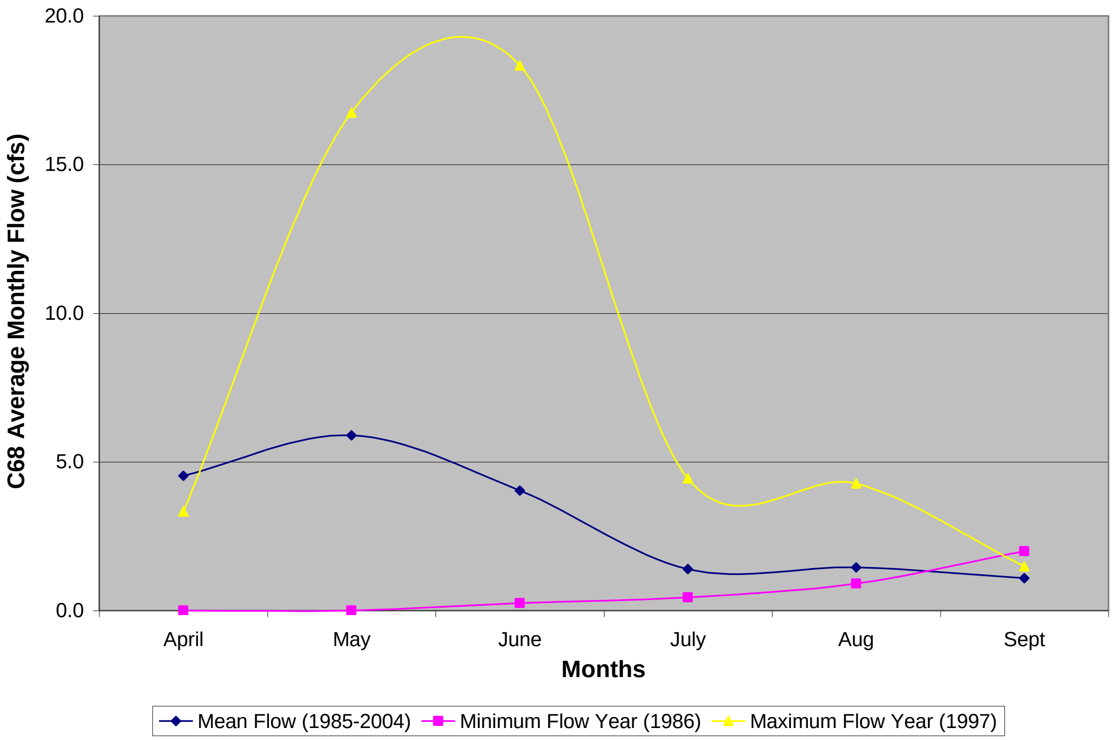


Figure 89. Mean, Minimum, and Maximum Annual Flows for C68 Gee Ditch

Flow in this ditch was correlated to Gage 10311700 minus the Cardelli and Quilici Ditches. There was no observable trend in April, so that month is defined by its mean. Regression analysis for May through September resulted in some weak observable trends. R^2 values ranged from a low of 0.10 for June and July to a high of 0.52 for August. Despite the very low R^2 value for June and July, the trend was visible and using the same logic as above, the trend was worth using. Results of the 1990-1999 simulation appear in Figure 90.

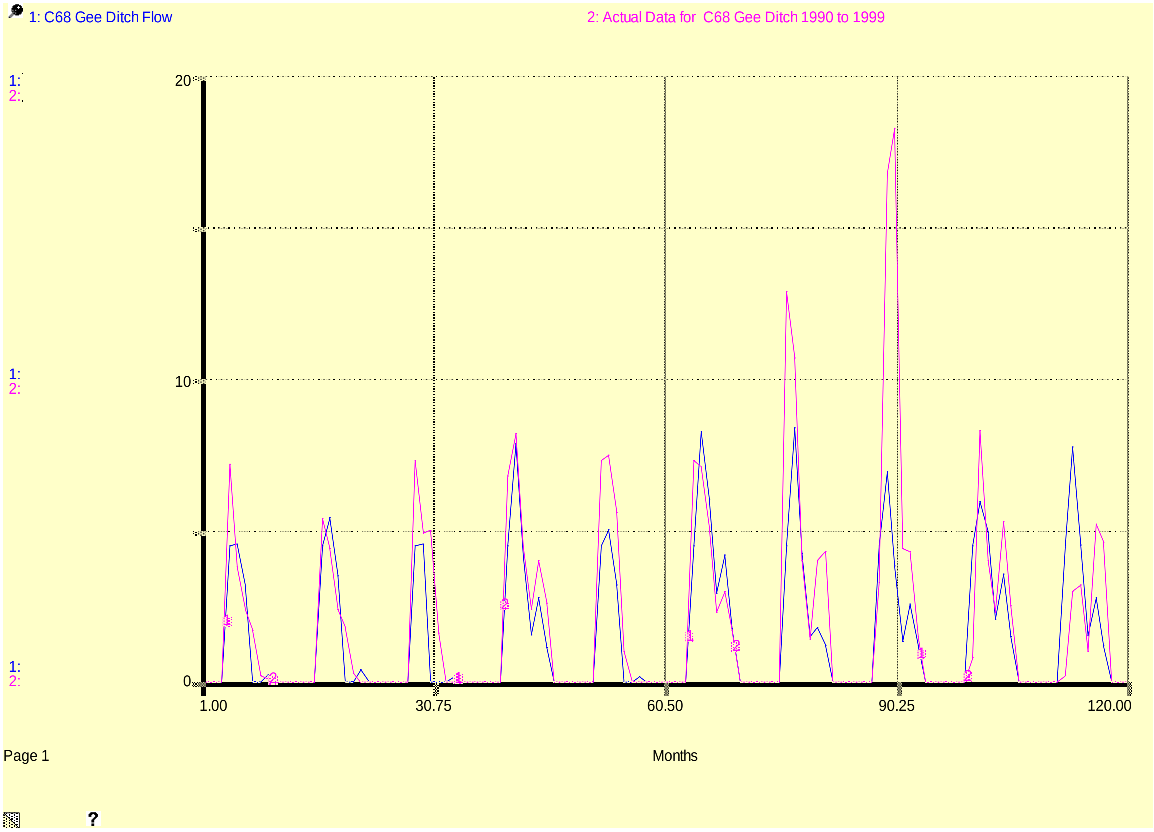


Figure 90. C68 Gee Ditch 1990-1999 Simulation, Actual vs. Model

Of particular note are the unusually high May flows of 1996 and 1997. Other than these abnormal peak flows, the model gives a reasonable depiction of the typical flow regime that peaks in May and then decreases throughout the summer with a slight increase in August.

C69 Koch Ditch

After the Gee Ditch, the Carson River supplies the Koch Ditch, which has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 1,998 acre-feet with a standard deviation of 564 acre-feet. The maximum total annual flow recorded at this gage is 3,089 acre-feet (1988). The minimum total annual flow recorded at this gage is 1,042 acre-feet (2001). Figure 91 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

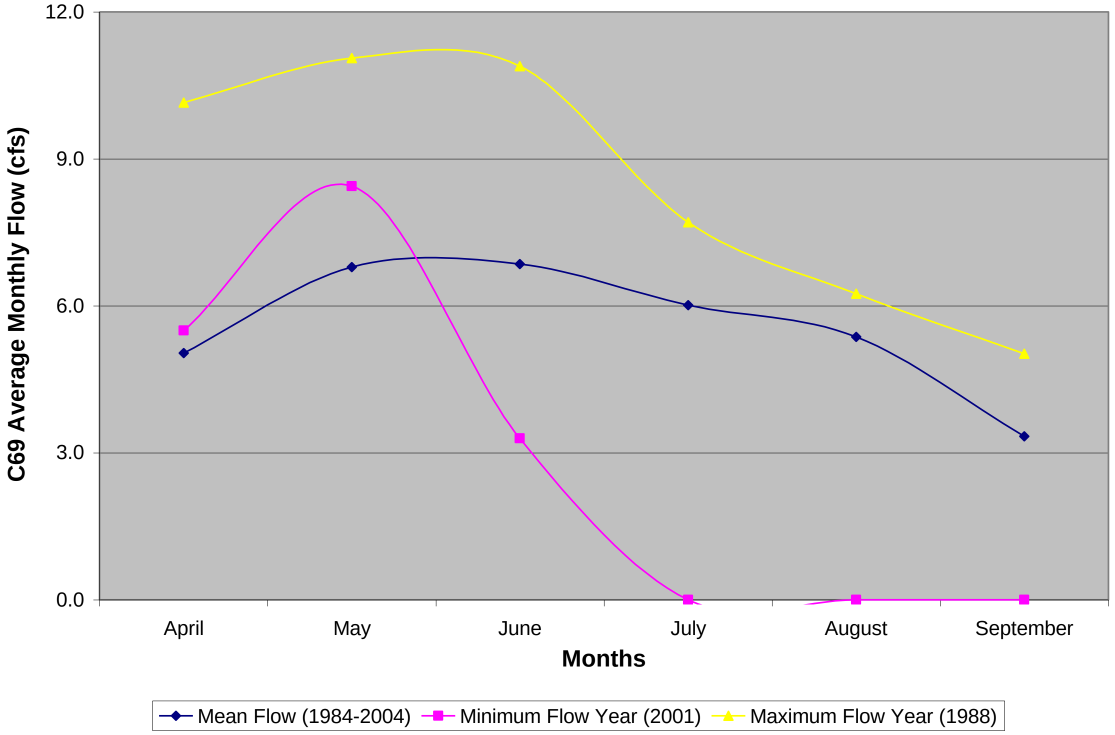


Figure 91. Mean, Minimum, and Maximum Annual Flows for C69 Koch Ditch

Flow in this ditch was correlated to Gage 10311700 minus the Cardelli, Quilici, and Gee ditches. Regression analysis for April through September resulted in some unique observable trends. In April through June, flow in the ditch was negatively correlated to flow in the river, meaning the higher the flows in the river, the lower the flows in the ditch. In July through September, there was a natural log relationship. The negative correlation in the spring may be due to a situation whereby Koch Ditch receives return flow from Cardelli Ditch and/or other sources during times of high river flow (after the gage), thus there is less need to attain water from the river itself during those months, and thus the lower gage measurement. In the latter part of the summer, Koch Ditch may become less reliant on these return flows and more dependant upon water directly from the river. This would explain the well correlated natural log trend lines for the latter part of the summer. R^2 values ranged from a low of 0.32 for June and July to a high of 0.69 for August. Results of the 1990-1999 simulation appear in Figure 92.

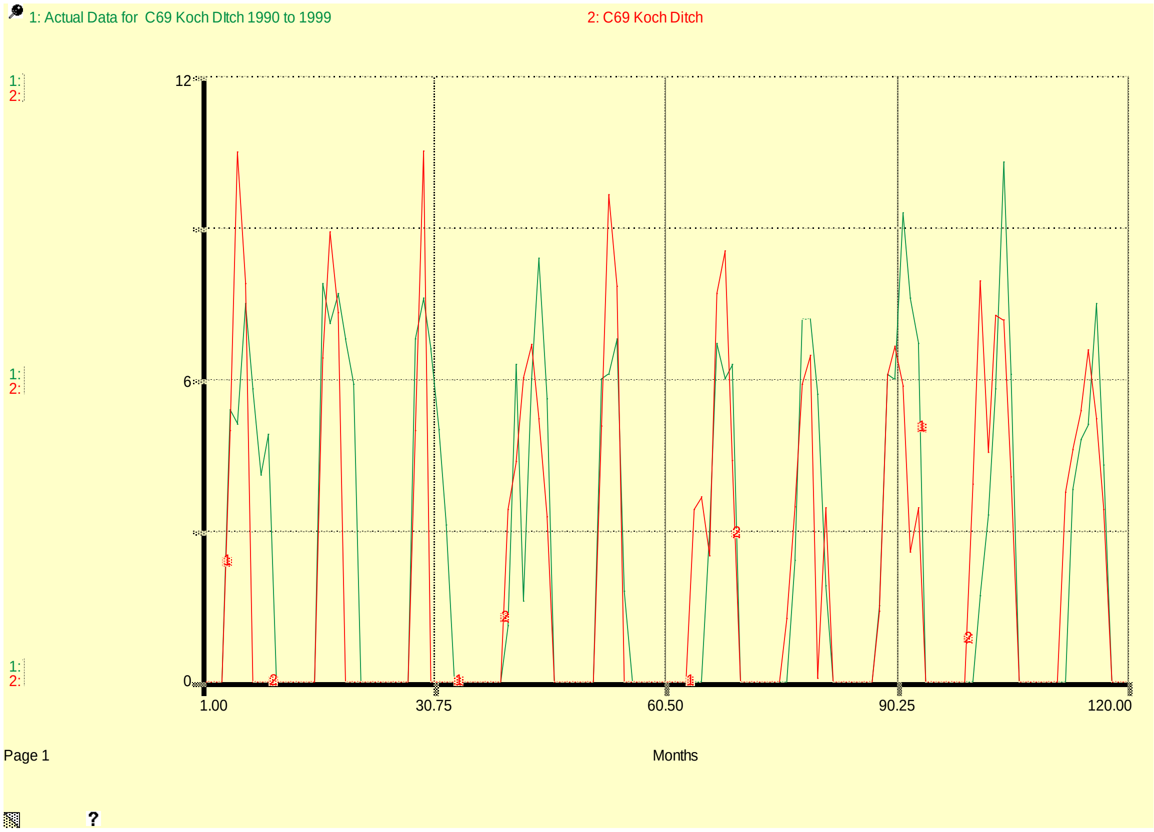


Figure 92. C69 Koch Ditch 1990-1999 Simulation, Actual vs. Model

The return flows scenario discussed above may be a trend for the 1984-2004 historical period of record, yet for the nineties, the spring trend is not as apparent.

Main Carson River Diversions: Churchill Valley Ditches

C70A Houghman and Howard Ditch

After the Koch Ditch, the Carson River supplies the Houghman and Howard Ditch, which has an historical record of 1985 and 1987-2004. Based on this record, the mean annual flow of this ditch is 1,283 acre-feet with a standard deviation of 491 acre-feet. The maximum total annual flow recorded at this gage is 3,089 acre-feet (1988). The minimum total annual flow recorded at this gage is 127 acre-feet (1987). The year 1986 had a lower total diversion of 0.0 acre-feet, however, the total zero diversion appears indicative of a decision not to irrigate at all, and thus was not counted in the historical record, as the historical record details years of actual flow. Figure 93 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

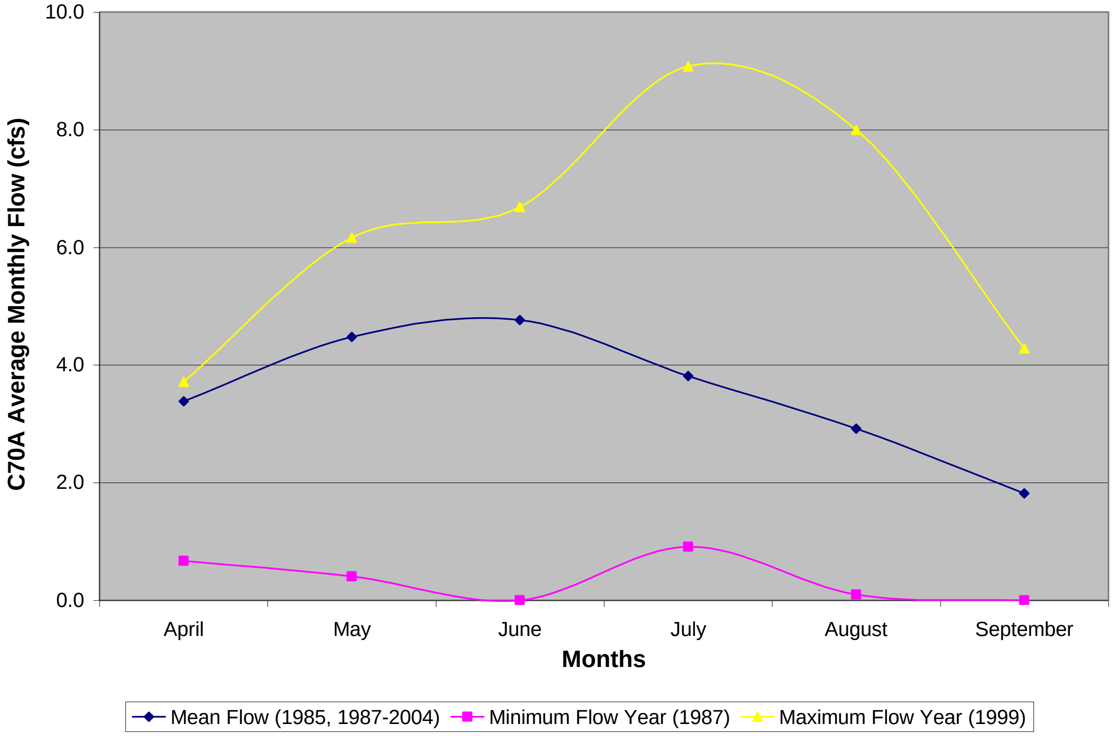


Figure 93. Mean, Minimum, and Maximum Annual Flows for C70A Houghman and Howard Ditch

Flow in this ditch was correlated to Gage 10311700 minus the Cardelli, Quilici, Gee, and Koch ditches. There was no observable trend in April through June, so those months are defined by their mean. Regression analysis for May through September resulted in some weak observable natural log trends. R^2 values ranged from a low of 0.22 for July to a high of 0.36 for September. Results of the 1990-1999 simulation appear in Figure 94.

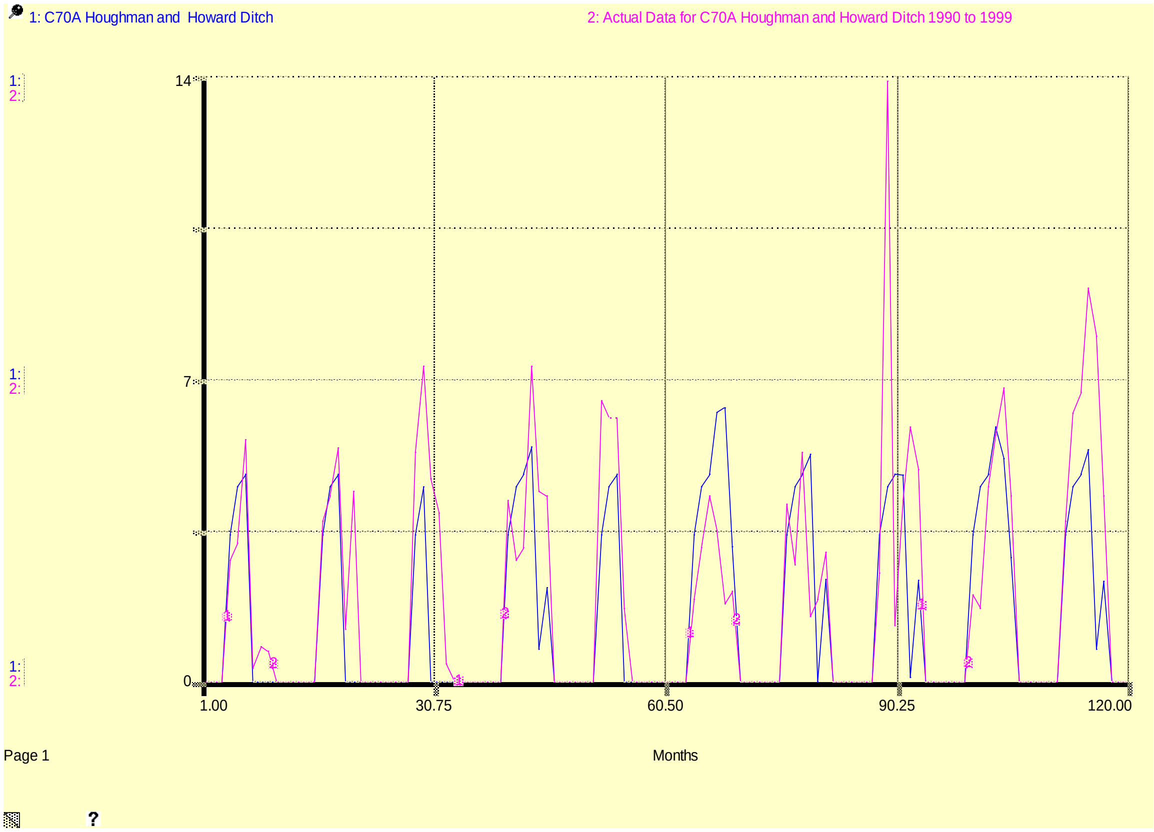


Figure 94. C70A Houghman and Howard Ditch 1990-1999 Simulation, Actual vs. Model

The model does a fair job predicting flow in most cases with exception to the under prediction of the abnormally high May flows of 1992 and 1997, the July flow of 1993, and the July and August flows of 1999. As with other diversion anomalies, these flows are likely related to independent decision making and/or other unusual events.

C71 Upper Buckland Ditch

After the Houghman and Howard Ditch, the Carson River supplies the last diversion prior to the river entering Lahontan Reservoir. This diversion is the Buckland Ditch, which has two separate gaging stations: one on the Upper Buckland Ditch and one on the Lower Buckland Ditch. The Upper Buckland Ditch has an historical record of 1984-2004. Based on this record, the mean annual flow of this ditch is 5,529 acre-feet with a standard deviation of 1,321 acre-feet. The maximum total annual flow recorded at this gage is 9,131 acre-feet (1997). The minimum total annual flow recorded at this gage is 3,104 acre-feet (1992). Figure 95 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

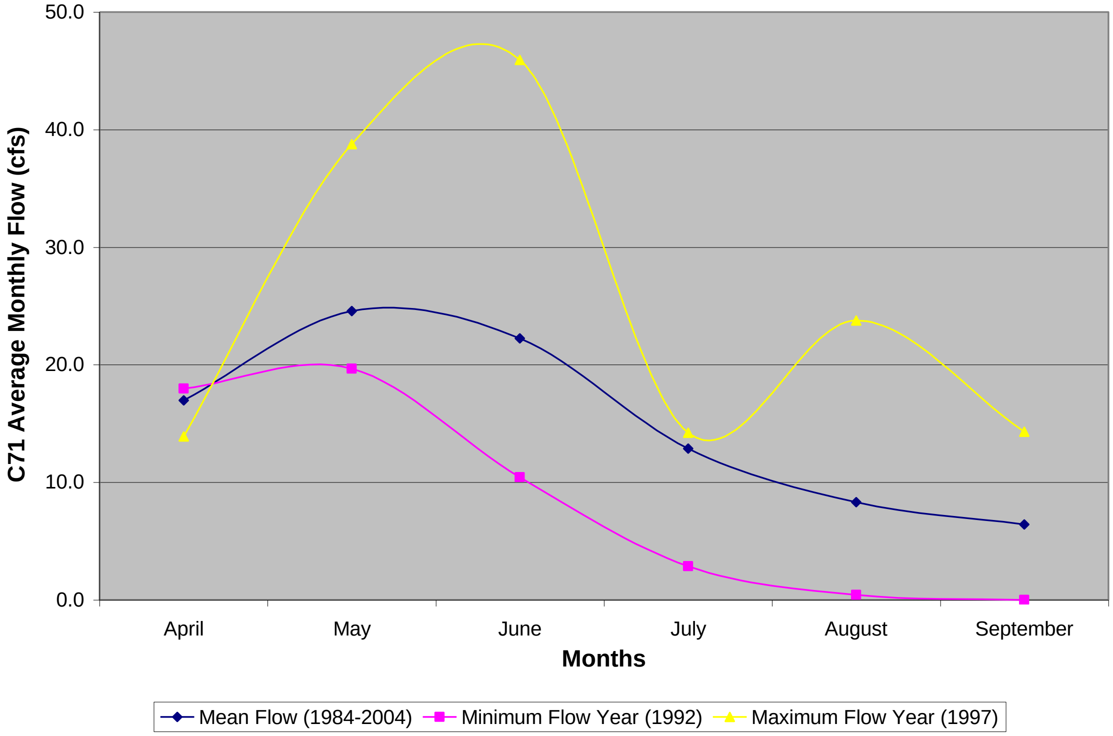


Figure 95. Mean, Minimum, and Maximum Annual Flows for C71 Upper Buckland Ditch

Flow in this ditch was correlated to Gage 10311700 minus the Cardelli, Quilici, Gee, Koch, and Houghman and Howard diversions. There was no observable trend in April and May, so those months are defined by their mean. Regression analysis for June through September resulted in fairly respectable natural log trends. R^2 values ranged from a low of 0.22 for June to a high of 0.72 for August. Results of the 1990-1999 simulation appear in Figure 96.

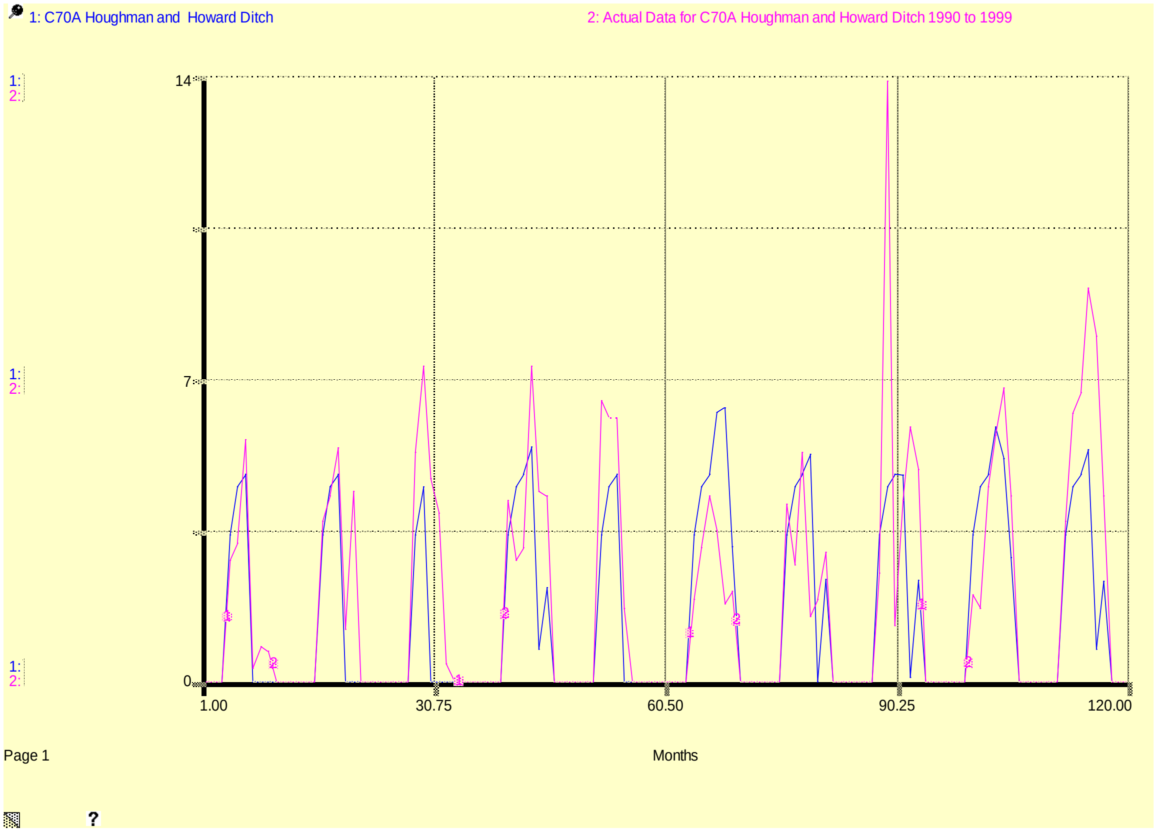


Figure 96. C701 Upper Buckland Ditch 1990-1999 Simulation, Actual vs. Model

For the most part, the model predicted flow is relatively consistent with actual flow. Noticeable exceptions are the under predictions of 1997 and 1999. As with other diversion anomalies, these flows are very inconsistent with historical practice, and as such, the model does not account for them.

C72 Lower Buckland Ditch

The lower Buckland Ditch is a downstream extension of the Upper Buckland Ditch and has an historical record of 1984-2002. In 2003 there was no recorded flow in this ditch, and in 2004 there were no flow measurements taken. Based on the historical record, the mean annual flow of the Lower Buckland Ditch is 2,963 acre-feet with a standard deviation of 909 acre-feet. The maximum total annual flow recorded at this gage is 4,702 acre-feet (1997). The minimum total annual flow recorded at this gage is 1,527 acre-feet (2001). Oddly, despite the fact that the Lower Buckland Ditch is merely an extension of the Upper Buckland Ditch, the two do not share the same low flow year. Figure 97 presents a graphical representation of this ditch's mean and extreme annual flows in cfs.

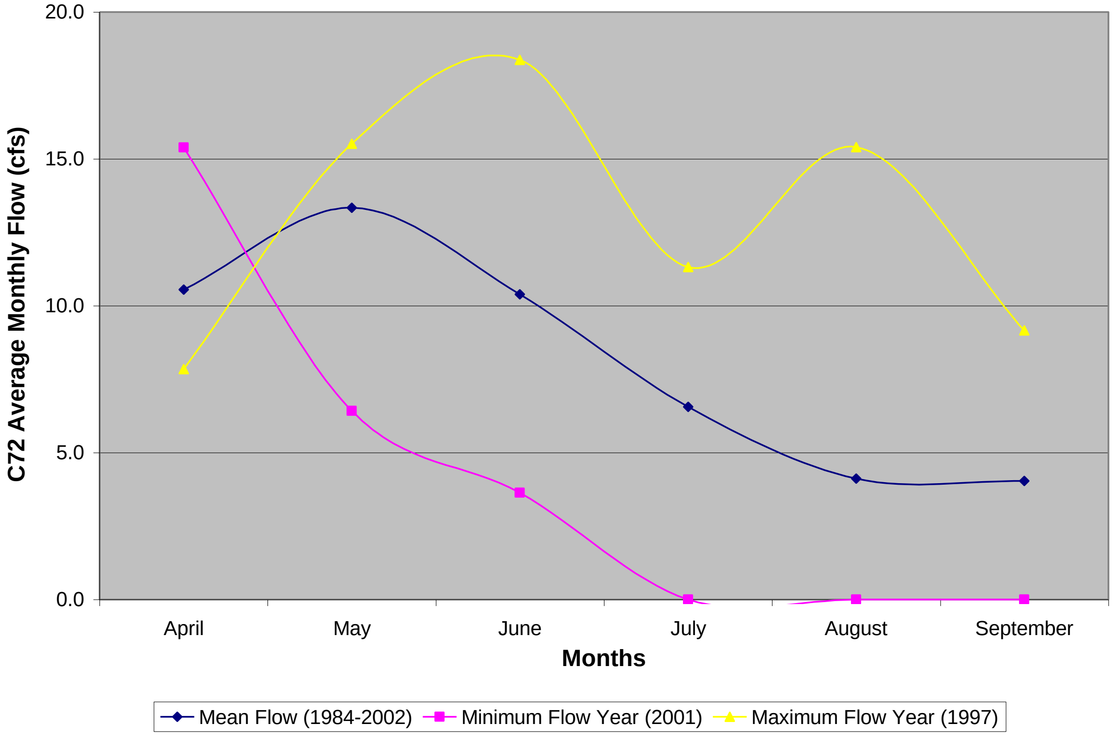


Figure 97. Mean, Minimum, and Maximum Annual Flows for C72 Lower Buckland Ditch

Flow in this ditch was correlated to the Upper Buckland Ditch. Given the direct input, regression analysis for April through September resulted in strong linear and natural log trends for most months. R^2 values ranged from a low of 0.32 for May to a high of 0.95 for September. Results of the 1990-1999 simulation appear in Figure 98.

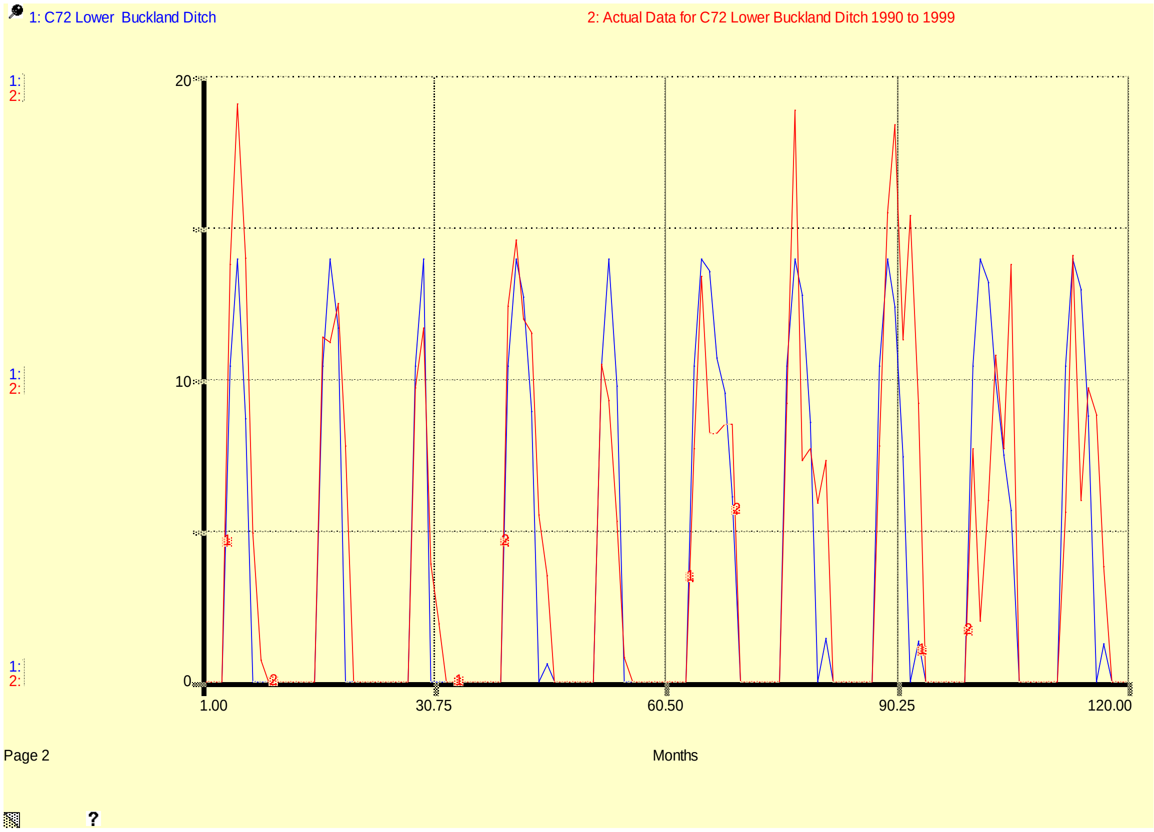


Figure 98. C72 Upper Buckland Ditch 1990-1999 Simulation, Actual vs. Model

As with the Upper Buckland Ditch, the model-predicted flow for the Lower Buckland is relatively consistent with some noticeable exceptions. The model under predicts 1990, 1997 and 1998. Interestingly, these years do not mirror the under predicted years of the Upper Buckland Ditch.

Main Carson River USGS Gages

There are four USGS Gages that record the flow of the main Carson River prior to the river's entrance into Lahontan Reservoir. The most upstream gage is Gage 10311000, which is located southeast of Carson City in between where Clear Creek flows into the Carson River and where outflow to Mexican Ditch begins. The next downstream gage is Gage 103100400, which is located northeast of Carson City just after the river turns east. The third gage, Gage 10311700, is located in Dayton. Gage 10312000 is the last USGS gage prior to Lahontan Reservoir and is located west of Fort Churchill.

Gage 10311000

Gage 10311000 is a USGS Gage with an historical record of 1940-current. Based on this record, the mean annual flow of this ditch is 295,115 acre-feet with a standard deviation of 174,763 acre-feet. The maximum total annual flow recorded at this gage is 860,942 acre-feet (1983). The minimum total annual flow recorded at this gage is 43,591 acre-feet (1977). Figure 99 presents a graphical representation of this gage's mean and extreme annual flows in cfs.

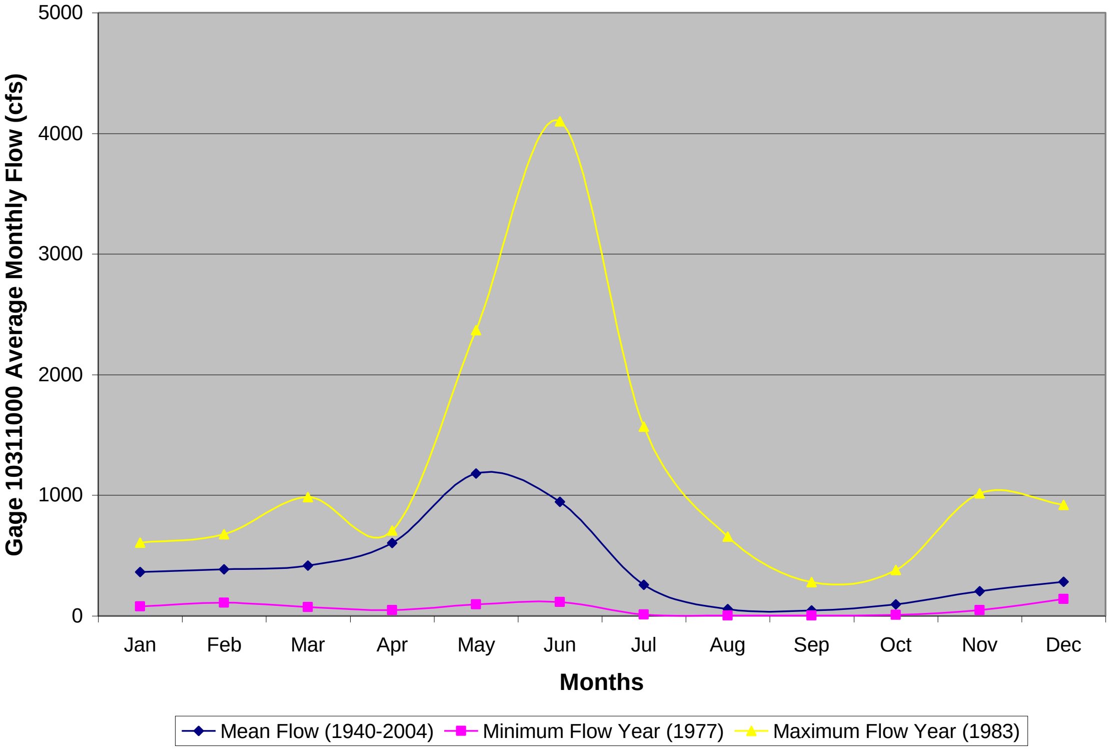


Figure 99. Mean, Minimum, and Maximum Annual Flows for Gage 10311000

Similar to all of the USGS gages discussed in this section, flow at this gage was not correlated to any other flow. Rather, in the model, flow simply passes through this gage, and the model predicted flow versus the actual flow was graphed. This graph was then used to inspect the model's accuracy. Results of the 1990-1999 simulation appear in Figure 100.

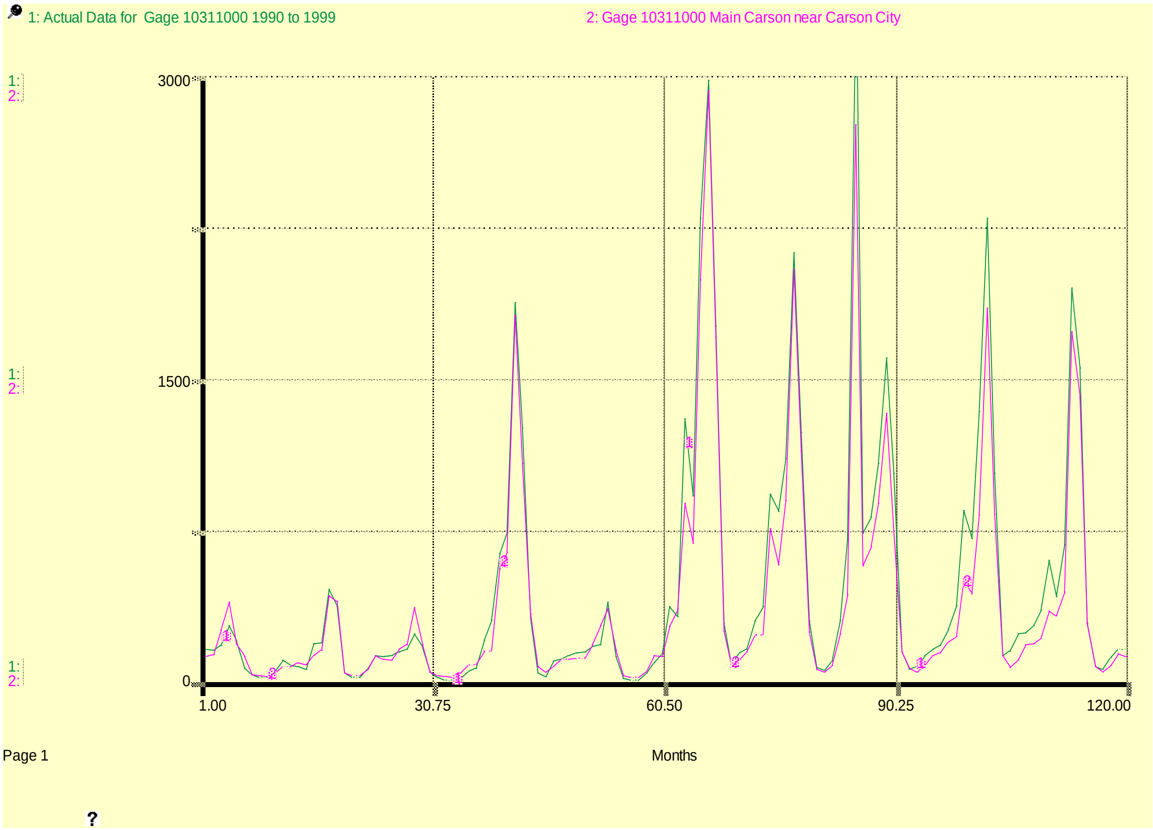


Figure 100. Gage 10311000 1990-1999 Simulation, Actual vs. Model

As can be seen, the model's overall prediction is quite close. Given the lack of gages on the river and the many estimates of diversion outflow and return flow prior to this point, the above represents a success. The modeled version of this gage is not without its issues, however. For example, the drought years of 1990 and 1992 are somewhat over predicted, and the wetter years of 1997 through 1999 are under predicted. The latter is not as much of a concern as the former, as one of the main purposes behind the model's creation is to predict the river's flow during times of normal or drought years, not wet years.

Gage 10311400

Gage 10311400 is a USGS Gage with an historical record of 1979-1985 and 1991-2004. Based on this record, the mean annual flow of this ditch is 351,881 acre-feet with a standard deviation of 235,046 acre-feet. Flow appears to be noticeably higher at this gage than the previous gage, located just six miles downstream. This is actually not the case. The discrepancy is due to the different period of record. In actuality, flow at the two gages is nearly identical, if examined in the context of the same year or same historical period of record. As the historical record is much shorter than the previous gage (and the last gage prior to Lahontan Reservoir), mean, maximum and minimum flow comparisons are not appropriate for this gage, nor for the following gage (Gage 10311700), which also has a brief historical record.

In the model, there is one key difference between this gage and the previous gage. As was discussed earlier in Section 5.3, the model has a component built into it that accounts for annual groundwater cycles. In the model, the cyclic flow of groundwater enters the river between this gage and the previous gage. Results of the 1990-1999 simulation appear below. No data is available for January through July of 1990.

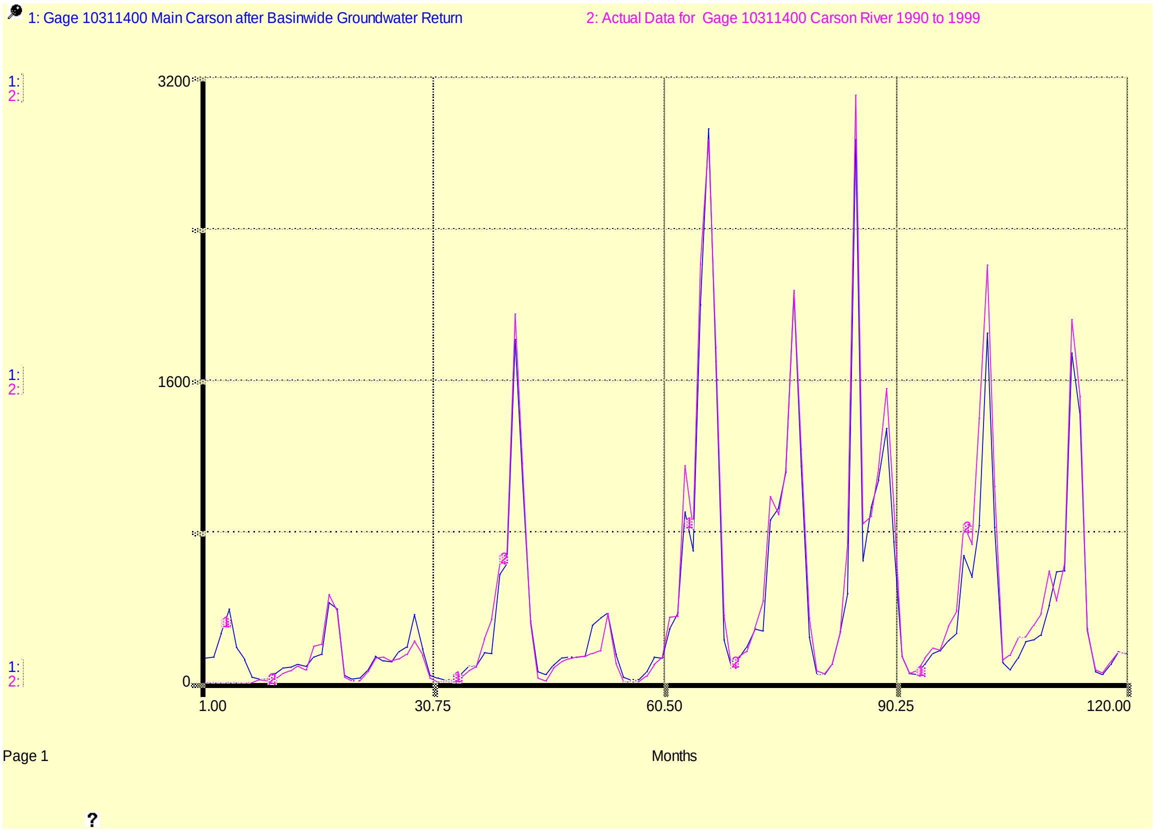


Figure 101. Gage 10311400 1990-1999 Simulation, Actual vs. Model

Because of the groundwater influx to the system, this modeled gage predicts more accurate results than the previous gage. Of note is the model's under prediction of the peak spring flows of 1998 and 1999 and the unique higher winter-early spring flow of 1998-1999. Similarly to discussions above, identifying the peak flows is not the main concern of this model, rather, correctly predicting low flows is more important. The abnormally high 1998-1999 winter flows is a different situation. The groundwater reservoir component to the model was meant to solve this modeling issue. It did to some extent, as the groundwater reservoir served to keep winter flows higher after successive years of heavy precipitation. However, flow in the Carson River during the winter of 1998-1999 was exceptionally high in comparison to historic winter flow. A method was not found whereby the reservoir would discharge more groundwater into the system in a winter similar to 1998-1999 without over compensating (over predicting) the winter flows of other, less wet years. It is recommended that work subsequent to this project consider other solution paths towards finding a remedy for this problem, should this sort of error become an issue in furthering the objectives of this project.

Gage 10311700

Gage 10311700 is a USGS Gage with an historical record of 1994-1997 and 2002-2004. Of those years, only 1995, 1996, and 2003 offer complete records. Because of this, discussion of historical records et al. is unwarranted. As with the above gage, this gage was used to test the accuracy of the model for the years in question. Results of the 1990-1999 simulation appear in Figure 102.

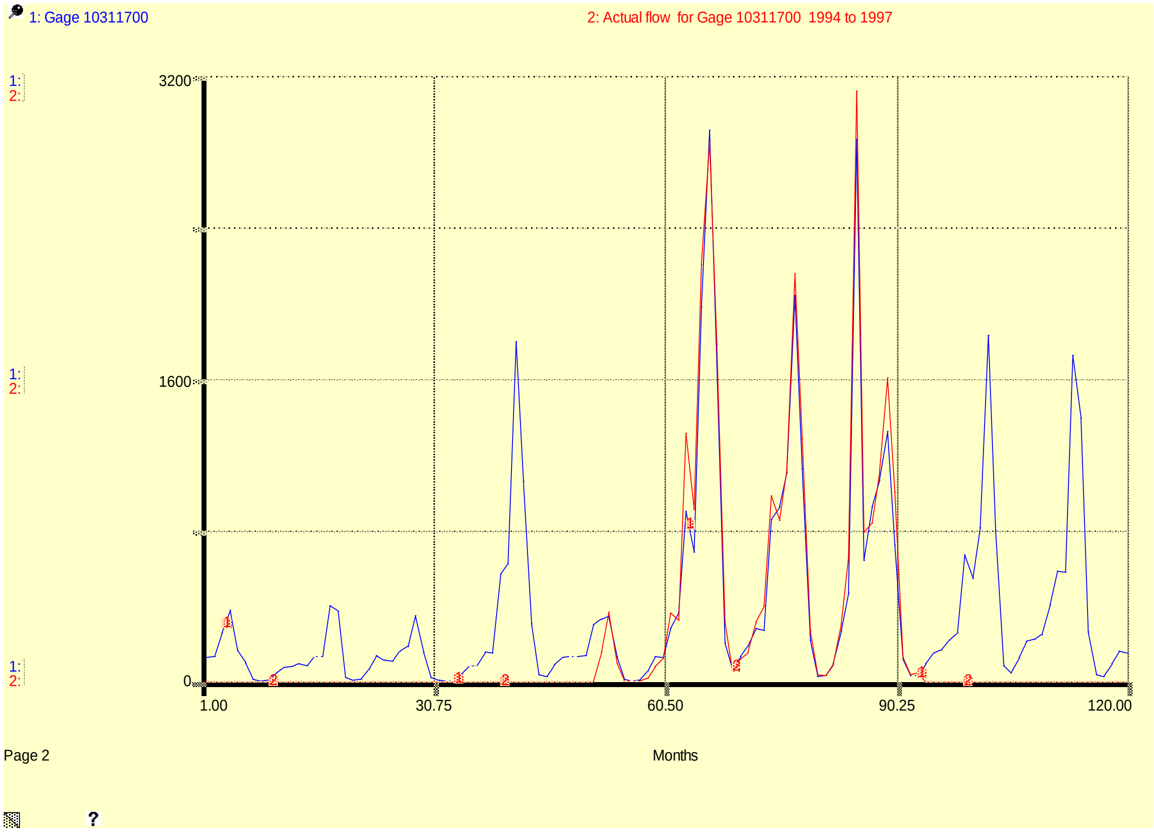


Figure 102. Gage 10311700 1990-1999 Simulation, Actual vs. Model

It is unfortunate that there is only a limited amount of monitored data for this gage, however, what is available provides evidence that the model is predicting accurate results. An obvious exception to this is the under prediction of March of 1995. The spring of 1995 was a very wet spring. This under prediction, then, is likely due to an abnormal precipitation runoff from sources outside the sphere of the model as well as runoff from precipitation directly in the valley.

Gage 10312000

Gage 10312000 is a USGS Gage with an historical record of 1911-2004. Based on this record, the mean annual flow of this ditch is 271,279 acre-feet with a standard deviation of 173,211 acre-feet. The maximum total annual flow recorded at this gage is 849.920 acre-feet (1983). The minimum total annual flow recorded at this gage is 25,743 acre-feet (1977). Figure 103 presents a graphical representation of this gage's mean and extreme annual flows in cfs.

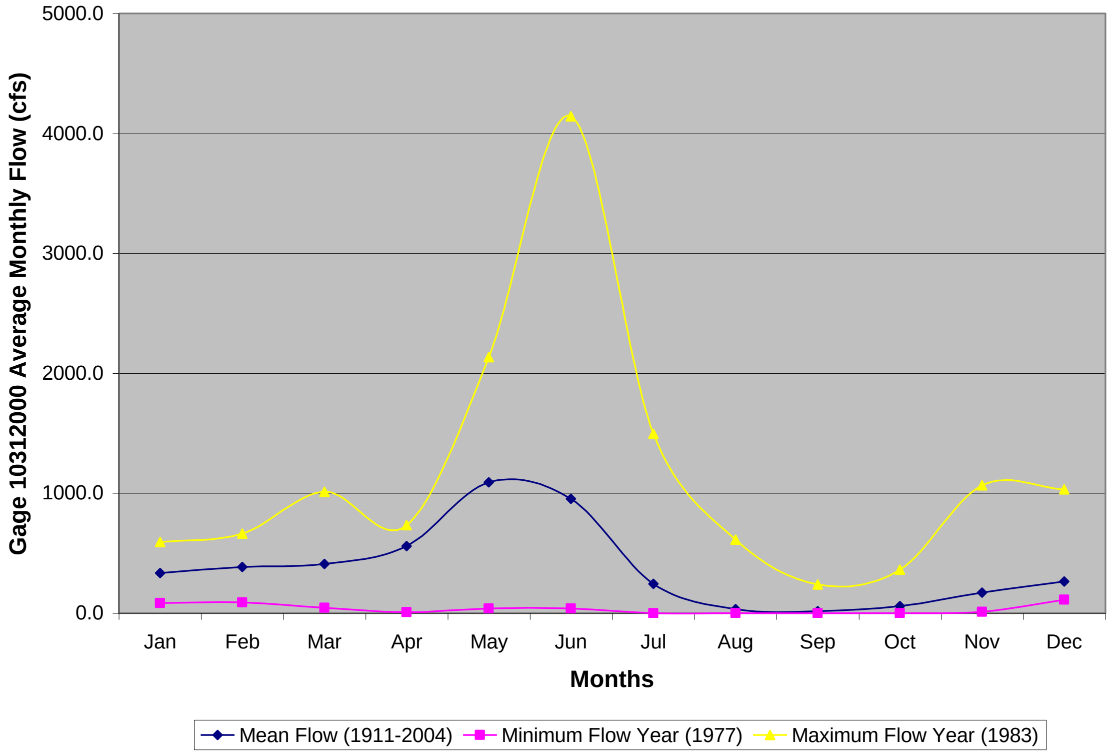


Figure 103. Mean, Minimum, and Maximum Annual Flows for Gage 10311000

As was seen in the previous section, the peak flow year also experienced a sizable increase in flow during March. The mean flow curve follows suit with what one would expect from a graph of a river that dedicates much of its waters to irrigation: a peak flow due to runoff in May followed by a decrease in flow to near zero during the irrigation season and then a gradual increase in flow during the winter. Results of the 1990-1999 simulation appear in Figure 104.

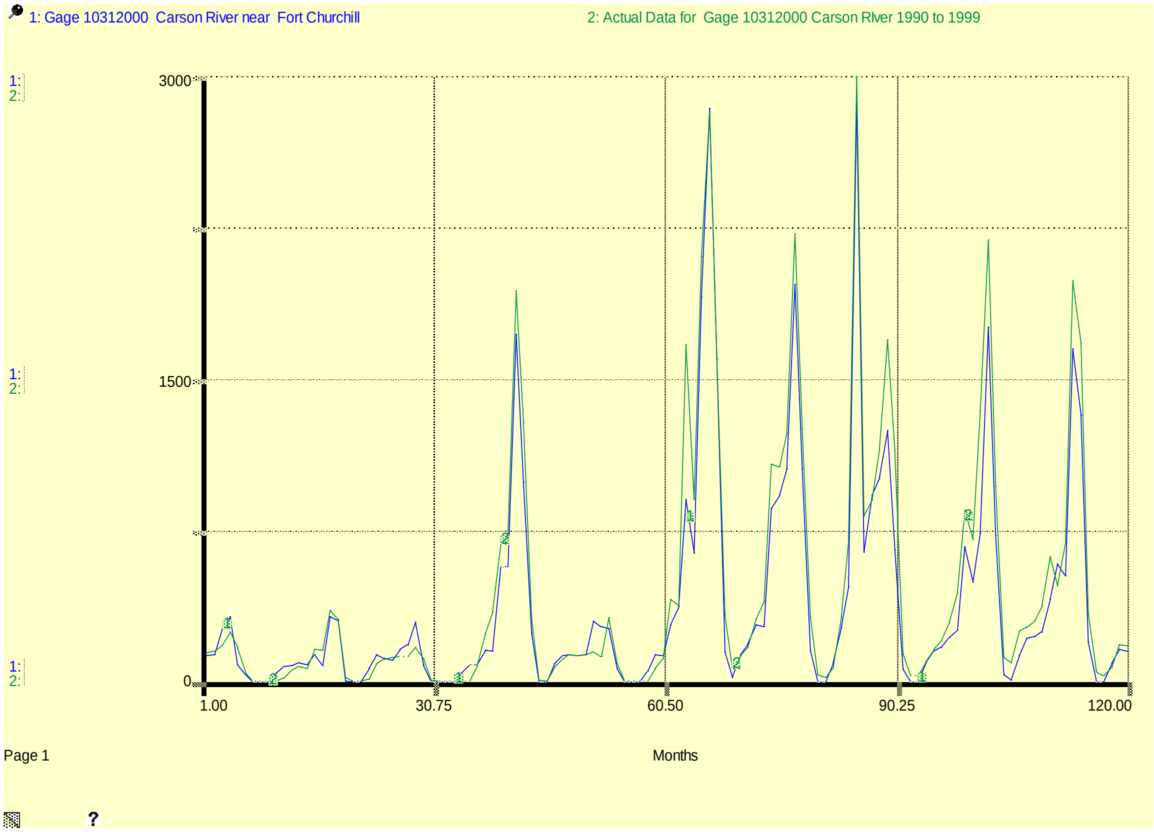


Figure 104. Gage 10312000 1990-1999 Simulation, Actual vs. Model

As with the previous gages, the model's overall prediction is relatively precise, yet there are some significant inaccuracies. April of 1990 and 1992 are somewhat over predicted as is March of 1994. Sizeable under predictions include February of 1996, March of 1998, June of 1996, 1997 and 1999, and July of 1998. It is unfortunate that the model does not under or over predict in the same months. If it did, the problem would be far easier to diagnose and solve. The problem likely lies with the model not taking into account localized conditions such as precipitation in the valley or very early/late runoffs. The above simulation, while not without its faults, is certainly representative of approximate flow conditions prior to Lahontan. Further, these results are accurate enough to achieve the objectives of this project. If feasible, more work could be done in subsequent studies to determine the source of this error and provide a remedy for the under and over predictions.

2.3.7 Model Summary

The Carson River is not a river in its natural state. While its headwater flow is controlled by the whims of nature, subsequent flow is largely controlled by humans operating within the framework and under the guidance of the Alpine Decree. An example of the human element can be seen by comparing the minimum and maximum flow years for the various diversions. Table 10 illustrates this point by comparing the 21 gaged diversions that, for the most part, share a common historic record of 1984-2004.

Table 10. Diversion Minimum and Maximum Flow Years

	Number of Diversions that Share this Statistic	
Year	**Minimum Flow Year**	**Maximum Flow Year**
1984		1
1985		1
1986	1	3
1987	3	
1988		1
1990	2	
1992	3	
1993		2
1994	2	
1995		3
1997		6
1999		3
2000		1
2001	7	
2003	1	
2004	2	

While there are some more common years for maximum and minimum flow, the variability is larger than one might expect from diversions that derive their water from the same source within the same basin.

This variability makes modeling the Carson River difficult. Despite this issue, however, the current model was able to predict flows with a fair level of accuracy. A common way to determine the effectiveness of a model is by calculating the root mean squared error (RMSE). The RMSE is found by taking the absolute value of the difference between the actual data and predicted values, summing those differences for the years in question, and then calculating the mean of those differences. The Carson River has three main gages along the mainstem of the river: Gages 10311000 (prior to Carson City), Gage 10311400 (after Carson City), and Gage 10312000 (prior to Fort Churchill). Table 11 shows the RMSEs for those three gages by month.

Table 11. Monthly Root Mean Squared Error for Main Carson River Gages

MONTH	Gage 10311000 RMSE	Gage 10314000 RMSE	Gage 10312000 RMSE
January	100	82	72
February	102	99	108
March	151	106	166
April	164	92	156
May	154	155	227
June	131	107	184
July	36	52	72
August	14	24	38
September	19	21	22
October	34	27	39
November	31	20	43
December	70	55	59

Table 11 reveals that Gage 10311400 is more accurate then Gage 10311000. This is because in the model, the groundwater reservoir enters the river between these two gages, and thus, a large source of groundwater is not reflected in Gage 10311000. Table 11 also reveals some issues with Gage 10312000. This gage's rather high RMSE is due to some precipitation anomalies that the model did not account for. These unusual events also inflated the RMSEs of the other two gages, though to a lesser degree, as Gage 10312000 picked up a significant amount of flood runoff from the valley.

For example, in May of 1997 and 1998, there was an unusually high amount of precipitation in the late spring. When these two years are removed from the data set, the mean May RMSE falls from 154 to 94 at Gage 10311000, from 155 to 88 at Gage 10311400, and from 227 to 152 at Gage 10312000. a one third decrease in all three gages. A similar situation occurred in March of 1995. When March of 1995 is removed, the mean March RMSE falls from 151 to 122 at Gage 10311000, from 106 to 88 at Gage 10311400, and from 166 to 98 at Gage 10312000. Other examples also exist. This is simply the nature of precipitation in the Sierras. An average year really only exists in forecasting terms. In actuality, nature typically causes an oscillation between drought and wet years, often with a few very wet or very dry years thrown in for good measure. As was previously discussed, the 1990s are a perfect example of this situation, which is why that particular decade was used: to test the model under the harshest conditions. Because of this, very low RMSEs were not (and should not be) expected.

As Table 10 and 11 illustrate, the river is difficult to model using mathematical relationships and coded governing logic. In order to plan for the future, decision makers need to make informed decisions. An integral factor in making informed decisions is having an understanding of the system that the decisions will affect. The purpose of this model and accompanying report is to increase this level of understanding with respect to the Upper Carson River Basin.

This project will meet its goal of providing a useful planning tool in the form of a model of the Upper Carson River Basin. Yet with the proper foresight, a more accurate understanding of the Upper Carson River Basin could be gained. Such increased understanding can occur if prudence is shown now or in the very near future by those who have the ability to aid current and future decision makers. In general, the model's accuracy suffers because of a lack of data. When put in context with how much revenue Carson River-based agriculture brings the State of Nevada - over $30 million/year in Churchill County alone (Horton, 1997b) - the added costs of attaining more data is relatively insignificant, while the benefits are compelling.

Decisions such as converting agriculture to municipal and industrial uses (M&I) have the potential to cause serious third party effects and could result in lawsuits. Lawsuits could also arise due to the failure of government to protect the public's resources. To decrease the chances of such negative consequences, decision makers should consider investments in collecting data that could help them better understand the system. Further, decision makers should understand as many of the relevant issues as they can. The following chapter addresses these issues.

3. Interface Development

The previous sections of this report describe the development of the integrated water resources planning model from the Carson River Basin down to Lahontan Reservoir. This section of the reports details the structure of the interface that allows planners and decision makers within the basin to utilize the planning model to provide information that facilitates both planning activities and communicating these actions to stakeholder that are affected by and engaged in watershed management activities in the Carson River watershed.

The user interface consists of four interrelated elements, these being:

(1) An introduction and navigations guidance element;
(2) A model documentation and reference element;
(3) A watershed learning and data access element; and
(4) A scenario development and analysis element.

Each of these elements are discussed below.

3.1 Interface Introduction and Navigation Element

The user interface is initiated by starting the STELLA© software package and loading the CARSONUI.STM (STELLA Model) or CARSONUI.STR (STELLA Runtime Model). The introduction screen is shown in Figure 105. As seen in the figure, the user can navigate to each of the interface elements by positioning the mouse arrow over the appropriate button and clicking the left mouse button.

To provide a context on the development and use of the integrated water resource planning tool the user can select the Introduction Button. This opens a dialog box (Figure 106) that provides the user with a narrative description on the purpose and intended use of the model. To return to the Introduction Screen, the user simply closes the text box. From this point, the user can navigate to each of the other interface elements.

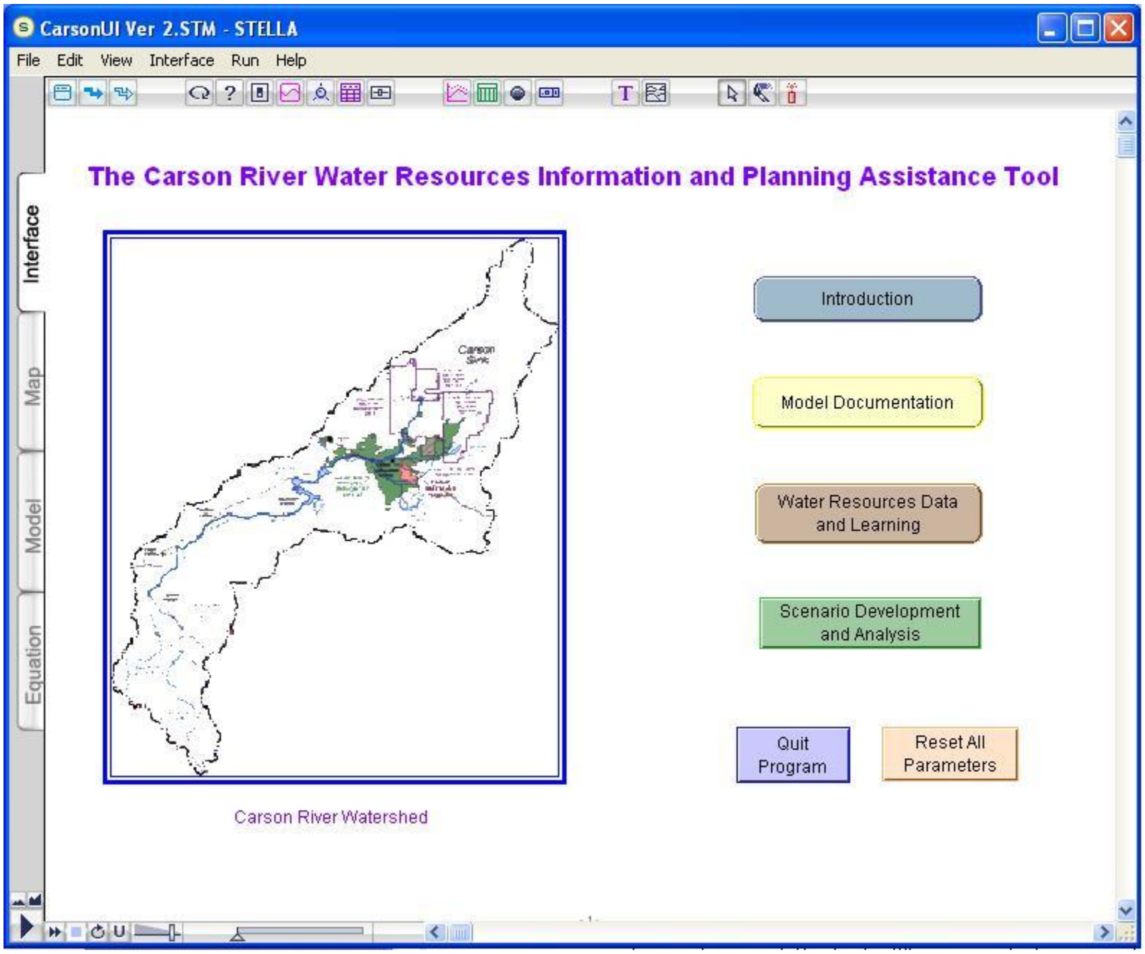


Figure 105. Interface Navigation and Introduction Screen.

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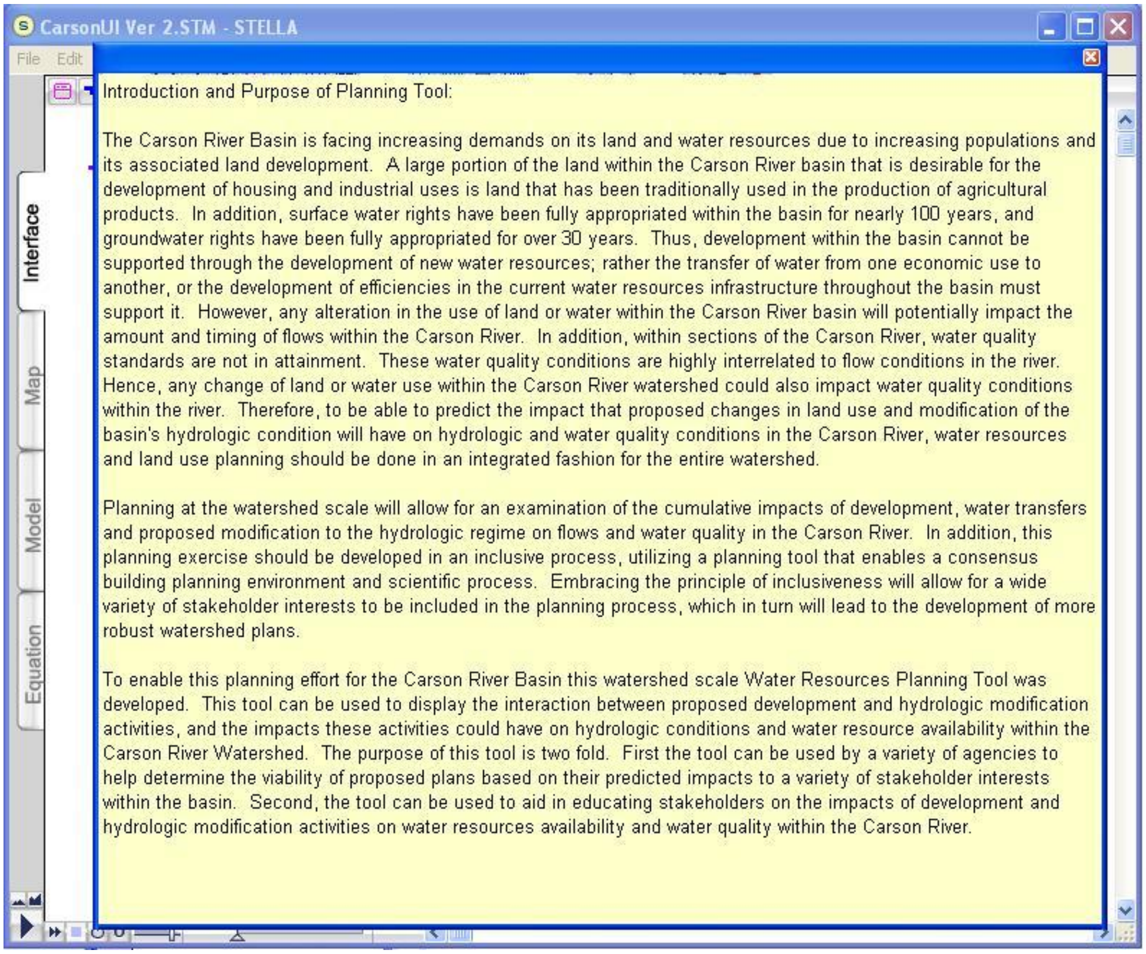


Introduction and Purpose of Planning Tool:

The Carson River Basin is facing increasing demands on its land and water resources due to increasing populations and its associated land development. A large portion of the land within the Carson River basin that is desirable for the development of housing and industrial uses is land that has been traditionally used in the production of agricultural products. In addition, surface water rights have been fully appropriated within the basin for nearly 100 years, and groundwater rights have been fully appropriated for over 30 years. Thus, development within the basin cannot be supported through the development of new water resources; rather the transfer of water from one economic use to another, or the development of efficiencies in the current water resources infrastructure throughout the basin must support it. However, any alteration in the use of land or water within the Carson River basin will potentially impact the amount and timing of flows within the Carson River. In addition, within sections of the Carson River, water quality standards are not in attainment. These water quality conditions are highly interrelated to flow conditions in the river. Hence, any change of land or water use within the Carson River watershed could also impact water quality conditions within the river. Therefore, to be able to predict the impact that proposed changes in land use and modification of the basin's hydrologic condition will have on hydrologic and water quality conditions in the Carson River, water resources and land use planning should be done in an integrated fashion for the entire watershed.

Planning at the watershed scale will allow for an examination of the cumulative impacts of development, water transfers and proposed modification to the hydrologic regime on flows and water quality in the Carson River. In addition, this planning exercise should be developed in an inclusive process, utilizing a planning tool that enables a consensus building planning environment and scientific process. Embracing the principle of inclusiveness will allow for a wide variety of stakeholder interests to be included in the planning process, which in turn will lead to the development of more robust watershed plans.

To enable this planning effort for the Carson River Basin this watershed scale Water Resources Planning Tool was developed. This tool can be used to display the interaction between proposed development and hydrologic modification activities, and the impacts these activities could have on hydrologic conditions and water resource availability within the Carson River Watershed. The purpose of this tool is two fold. First the tool can be used by a variety of agencies to help determine the viability of proposed plans based on their predicted impacts to a variety of stakeholder interests within the basin. Second, the tool can be used to aid in educating stakeholders on the impacts of development and hydrologic modification activities on water resources availability and water quality within the Carson River.

Figure 106**.** Narrative description of Model and Interface Purpose.

3.2 Documentation Element

Many times, users of a planning tool such as this find it more convenient to learn about the model and interface in a ‘learning by doing’ style. That is, it is more convenient, as well as efficient, to have a tool that does not inherently require the reading of a users manual prior to use of the tool. This user interface was developed with this learning strategy in mind. Hence, much of the documentation of the model development (Chapter 2 of this report) is provided as a part of the interface. When the user selects the Model Documentation and Reference button from the main navigation screen, they are taken to a new screen (Figure 107) that allow them to view the assumptions and mathematical representations used for specific model elements, the significant references that were used to develop these relationships and how the model elements were linked together. The user can select the References Button to view the entire report bibliography (Figure 108). To return to the Model Documentation and Reference screen the user can simply close the Reference Dialogue box.

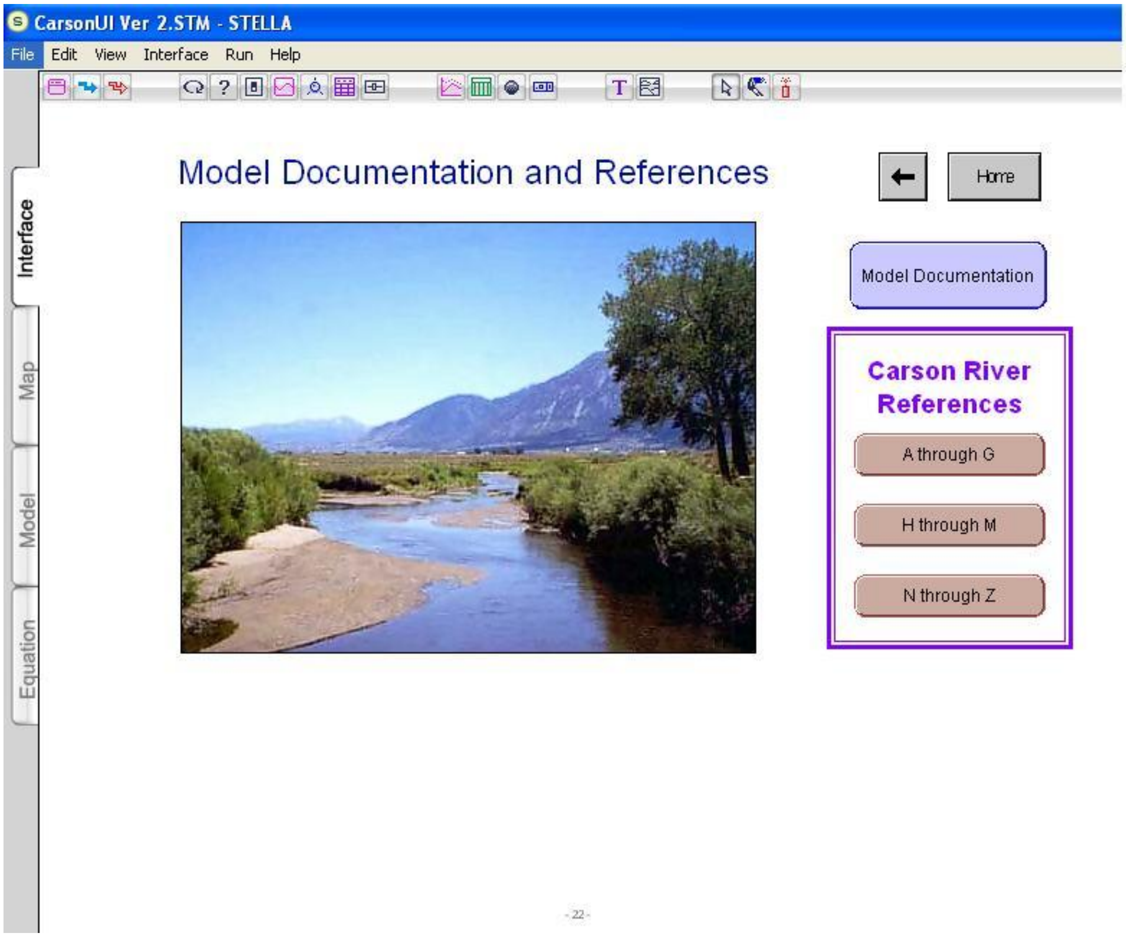
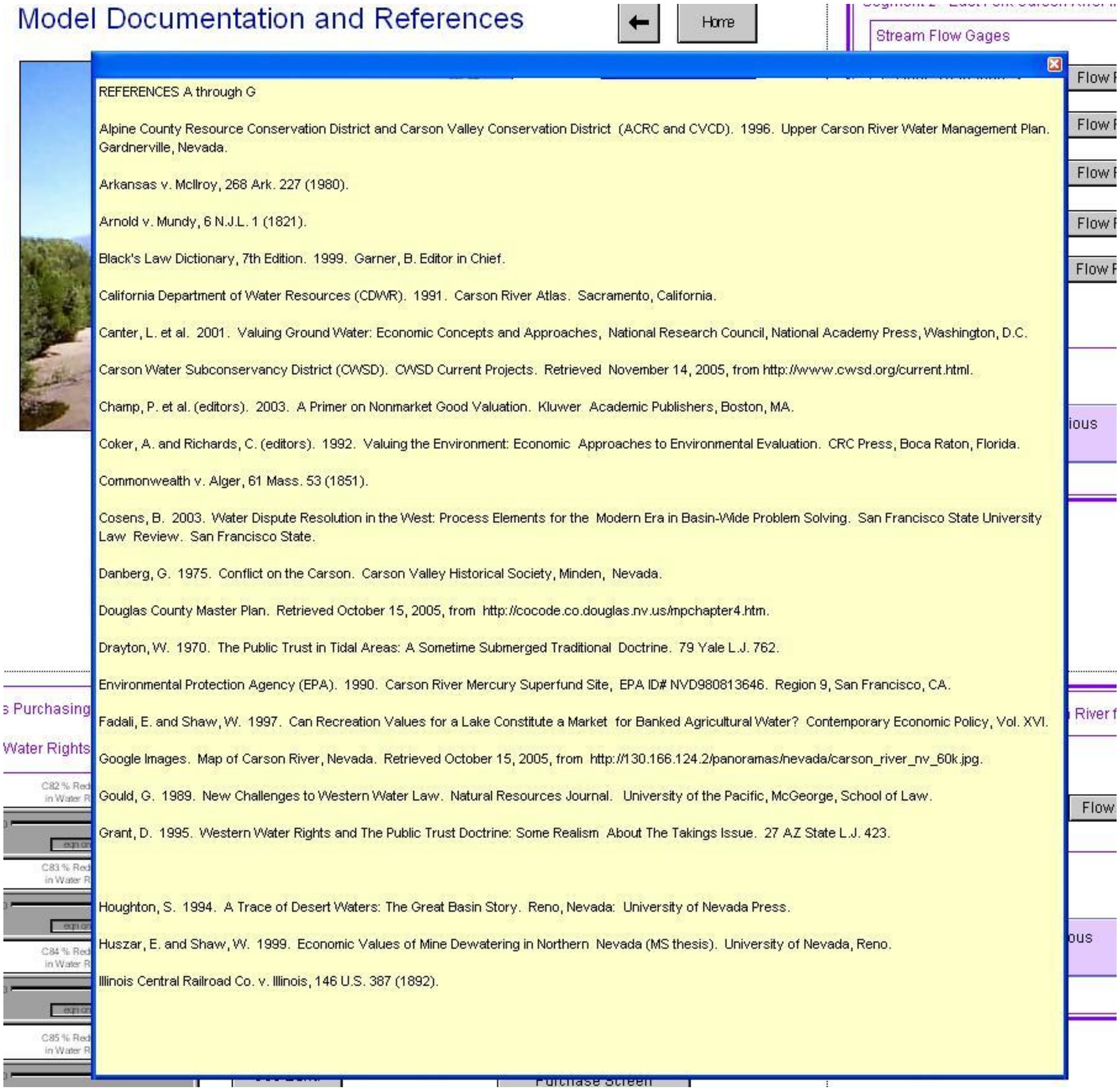


Figure 107. Model Documentation and Reference Screen.



REFERENCES A through G

Alpine County Resource Conservation District and Carson Valley Conservation District (ACRC and CVCD). 1996. Upper Carson River Water Management Plan. Gardnerville, Nevada.

Arkansas v. McIlroy, 268 Ark. 227 (1980).

Arnold v. Mundy, 6 N.J.L. 1 (1821).

Black's Law Dictionary, 7th Edition. 1999. Garner, B. Editor in Chief.

California Department of Water Resources (CDWR). 1991. Carson River Atlas. Sacramento, California.

Canter, L. et al. 2001. Valuing Ground Water: Economic Concepts and Approaches, National Research Council, National Academy Press, Washington, D.C.

Carson Water Subconservancy District (CWSD). CWSD Current Projects. Retrieved November 14, 2005, from http://www.cwsd.org/current.html.

Champ, P. et al. (editors). 2003. A Primer on Nonmarket Good Valuation. Kluwer Academic Publishers, Boston, MA.

Coker, A. and Richards, C. (editors). 1992. Valuing the Environment: Economic Approaches to Environmental Evaluation. CRC Press, Boca Raton, Florida.

Commonwealth v. Alger, 61 Mass. 53 (1851).

Cosens, B. 2003. Water Dispute Resolution in the West: Process Elements for the Modern Era in Basin-Wide Problem Solving. San Francisco State University Law Review. San Francisco State.

Danberg, G. 1975. Conflict on the Carson. Carson Valley Historical Society, Minden, Nevada.

Douglas County Master Plan. Retrieved October 15, 2005, from http://cocode.co.douglas.nv.us/mpchapter4.htm.

Drayton, W. 1970. The Public Trust in Tidal Areas: A Sometime Submerged Traditional Doctrine. 79 Yale L.J. 762.

Environmental Protection Agency (EPA). 1990. Carson River Mercury Superfund Site, EPA ID# NVD980813646. Region 9, San Francisco, CA.

Fadali, E. and Shaw, W. 1997. Can Recreation Values for a Lake Constitute a Market for Banked Agricultural Water? Contemporary Economic Policy, Vol. XVI.

Google Images. Map of Carson River, Nevada. Retrieved October 15, 2005, from http://130.166.124.2/panoramas/nevada/carson_river_nv_60k.jpg.

Gould, G. 1989. New Challenges to Western Water Law. Natural Resources Journal. University of the Pacific, McGeorge, School of Law.

Grant, D. 1995. Western Water Rights and The Public Trust Doctrine: Some Realism About The Takings Issue. 27 AZ State L.J. 423.

Houghton, S. 1994. A Trace of Desert Waters: The Great Basin Story. Reno, Nevada: University of Nevada Press.

Huszar, E. and Shaw, W. 1999. Economic Values of Mine Dewatering in Northern Nevada (MS thesis). University of Nevada, Reno.

Illinois Central Railroad Co. v. Illinois, 146 U.S. 387 (1892).

Figure 108. Model Reference Dialogue Box.

The user can then view the overall model structure by selecting the Documentation Button, opening a Model Learning screen. The model learning screen (Figure 109) allows the user to step through each of the model elements and view how water moves through the Carson River watershed. The ‘stepping’ through the model is done by using the space bar or the left mouse button. Each element has a narrative statement on the mathematical relationship used to represent it in the overall model and how this relationship was developed. The user can return to either the Model Documentation screen by clicking the Return Button in the upper right hand corner of the screen or return to the Main Navigation Screen by selecting the Home Button.

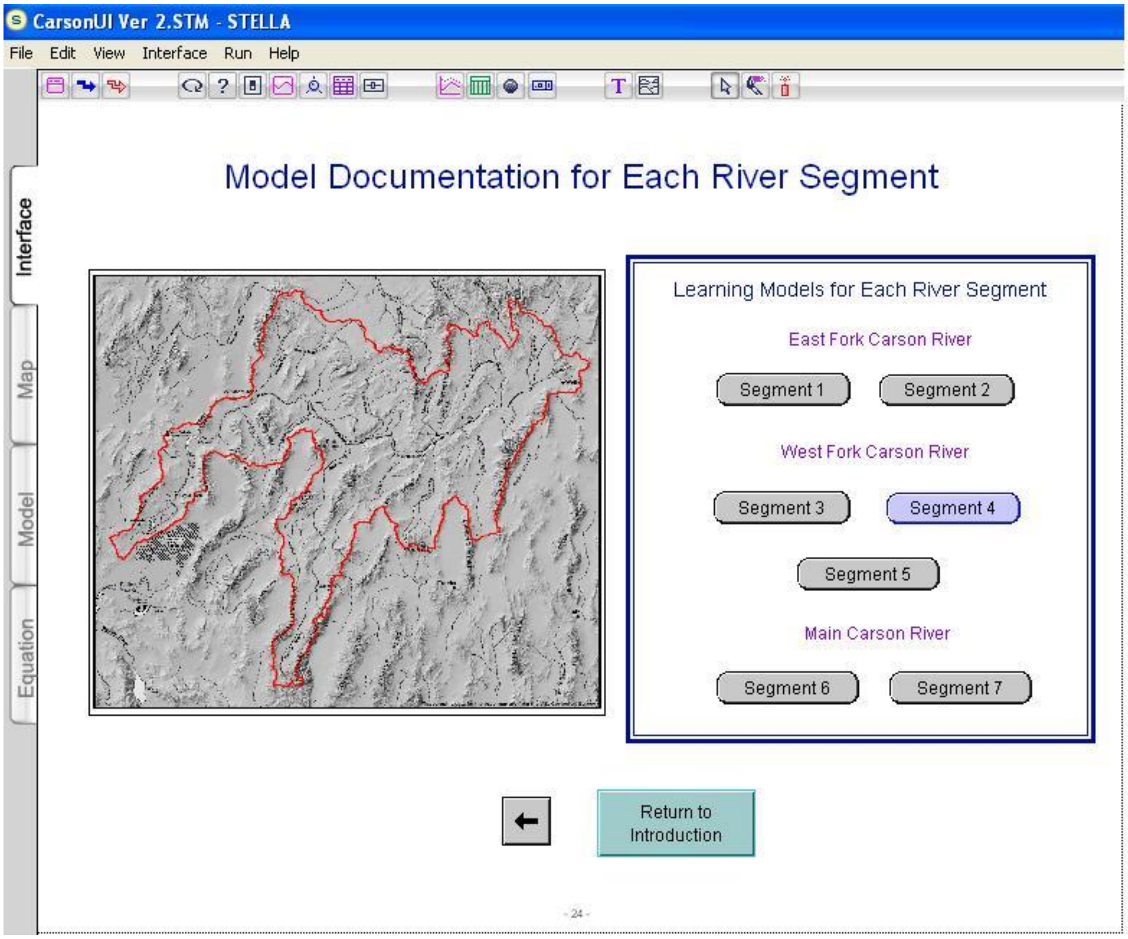
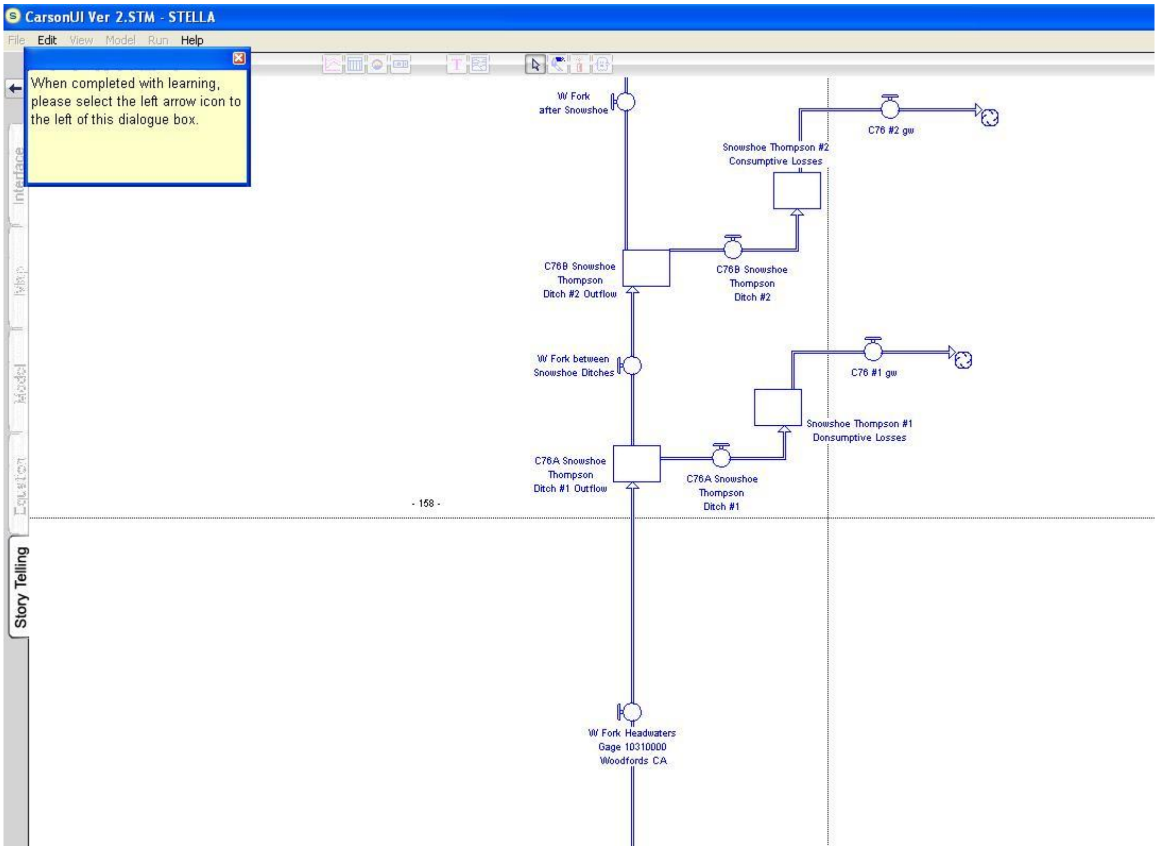


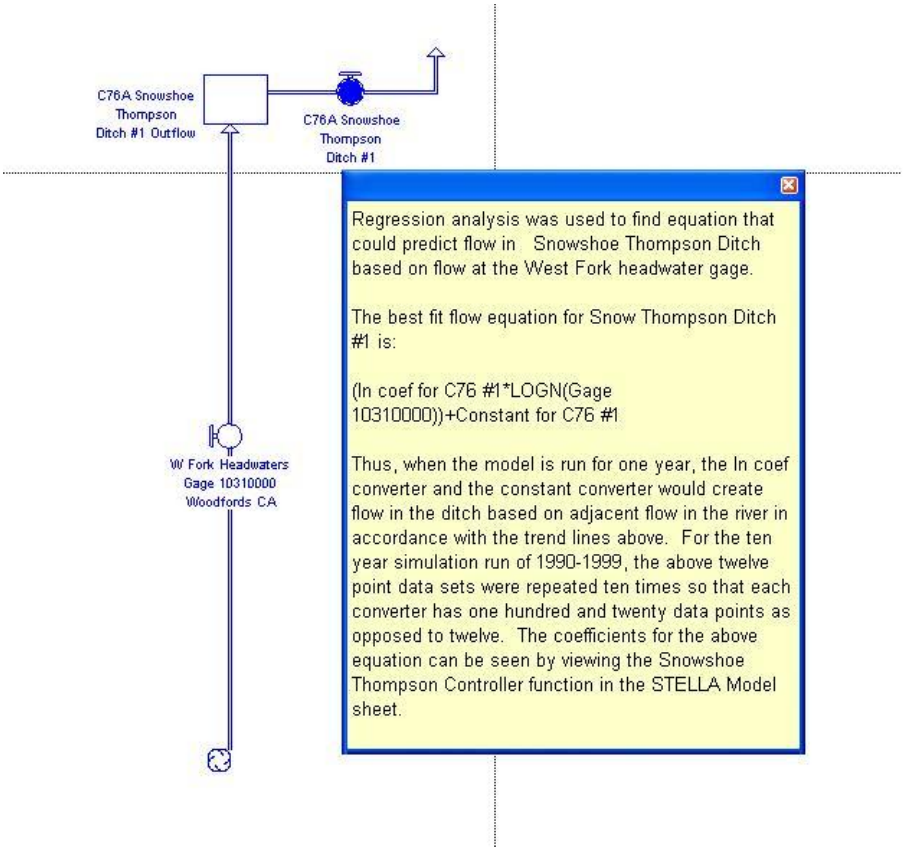
Figure 109. Model Documentation Screen.

Finally, users can view in detail the development of each model element by selecting the model Learning button, which takes the user to the Learning Screen for each Segment of the Carson River (Figure 110). This screen allows the user to view a detailed description of each model process by selecting the appropriate button. For example, if the user wishes to explore how Segment 3 of the West Carson River was developed, the user can select this button. The user can then step through each element used to simulate water movements in Segment 3. An example of this is shown for the Snowshoe Thompson Ditch # 1 diversion in Figure 111. To return to the Model Documentation Screen, the user simply selects the left arrow in the upper left hand corner of the learning screen.



When completed with learning, please select the left arrow icon to the left of this dialogue box.

Figure 110. Learning Screen for River Segment 3



Regression analysis was used to find equation that could predict flow in Snowshoe Thompson Ditch based on flow at the West Fork headwater gage.

The best fit flow equation for Snow Thompson Ditch #1 is:

(ln coef for C76 #1*LOGN(Gage 10310000))+Constant for C76 #1

Thus, when the model is run for one year, the ln coef converter and the constant converter would create flow in the ditch based on adjacent flow in the river in accordance with the trend lines above. For the ten year simulation run of 1990-1999, the above twelve point data sets were repeated ten times so that each converter has one hundred and twenty data points as opposed to twelve. The coefficients for the above equation can be seen by viewing the Snowshoe Thompson Controller function in the STELLA Model sheet.

Figure 111 Snowshoe Thompson Example for Model Learning Screen.

3.3 Learning and Data Access Element

This portion of the interface provides an opportunity for the user to become educated on the hydrology and water resources management within the Carson River watershed. When the user selects the Learning and Data Access button from the main interface screen, they are taken to the Data Access Screen (Figure 112). The user can view historical data on stream flows and diversion rates at monitored locations within the Carson River watershed. The historical data is organized by river segments that are defined in the Alpine Decree (see Section 1.6.2). The user can view the data available for each section of the Carson River by selecting the appropriate button. Then, the user can view either historical stream flow data or historical diversion data by selecting the appropriate button. For example, if stream flow and diversion data for stream Segment 4, the user would select the Segment 4 button, which would open the Segment 4 screen (Figure 113). The user can view the average annual flow statistics for each stream gage in this river segment by selecting the appropriate button. For example, if the user selected the Gage 10310000 button a dialogue box appears that contains these statistics (Figure 114). The user can then view graphs of the historical monthly stream flows and the monthly average stream flows at this gage by selecting the Gage 10310000 Flow Rates button (Figure 115). The user can also view summary statistics and graphs of the recorded diversions within this segment of the river by selecting the appropriate button.

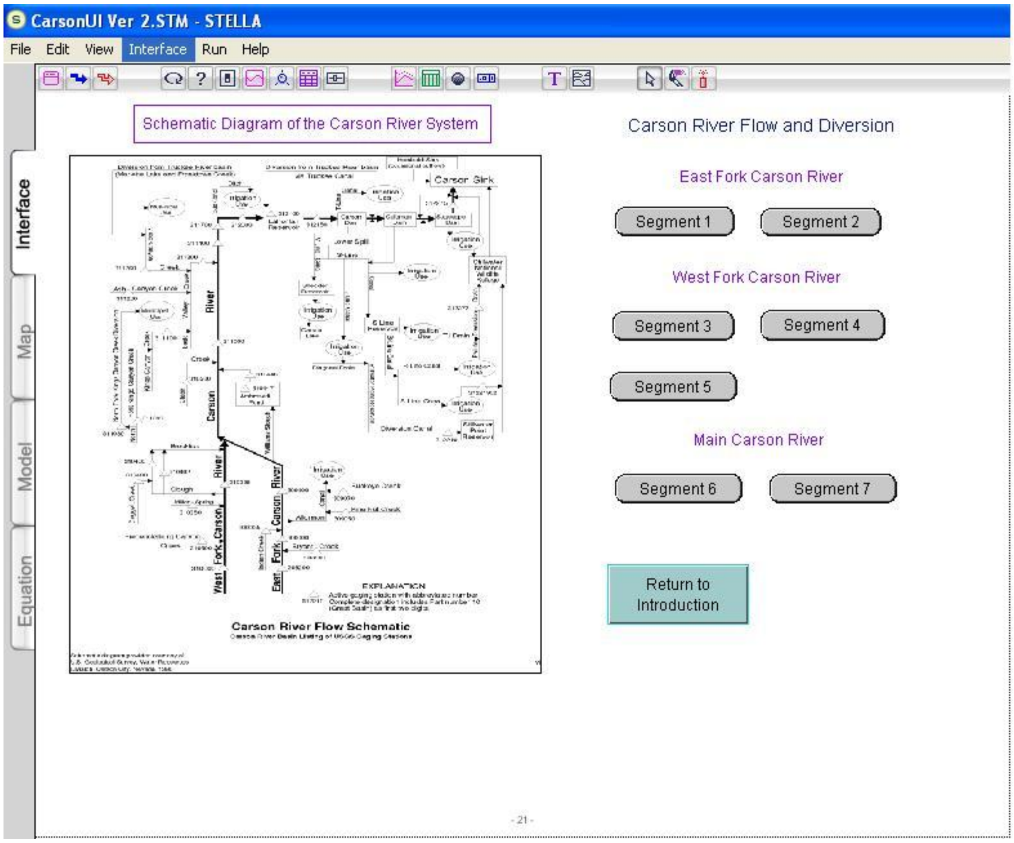


Figure 112 Interface Data Access Screen.

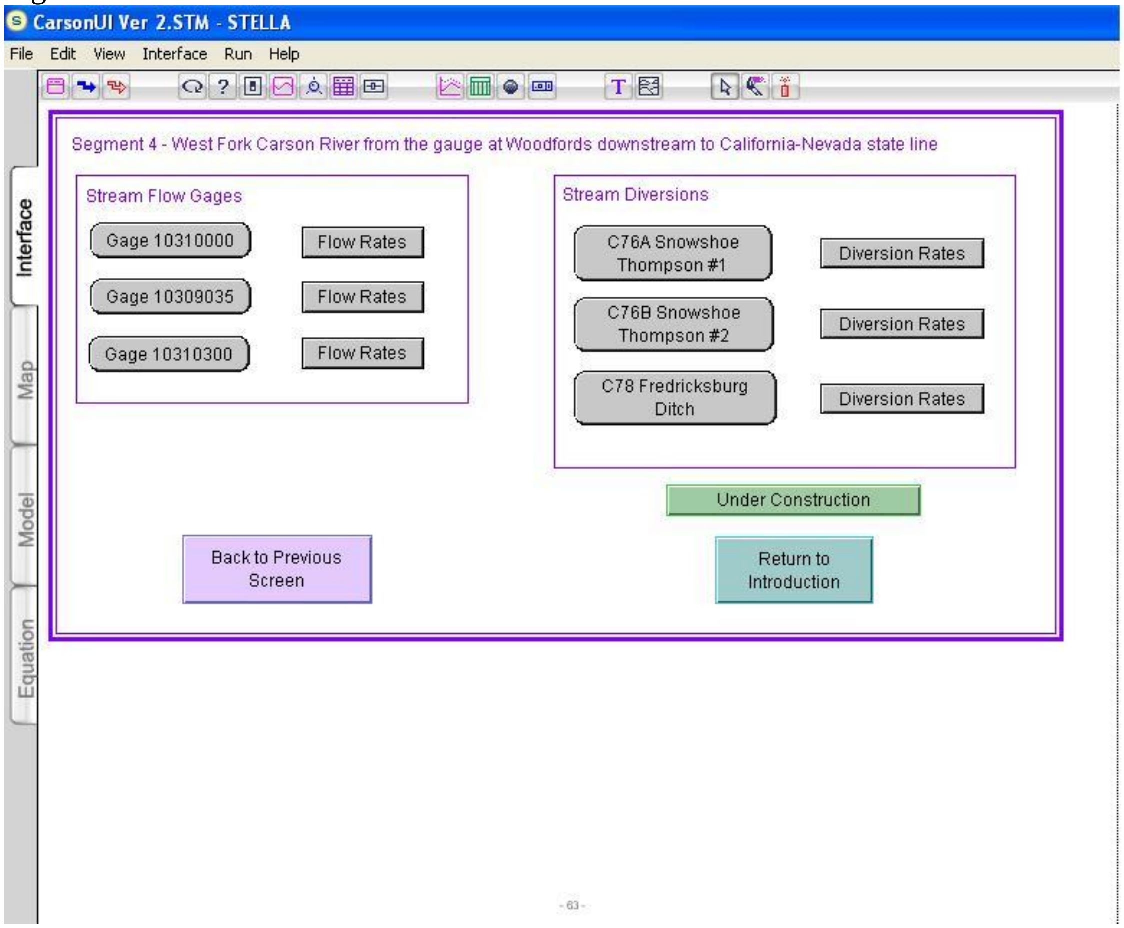
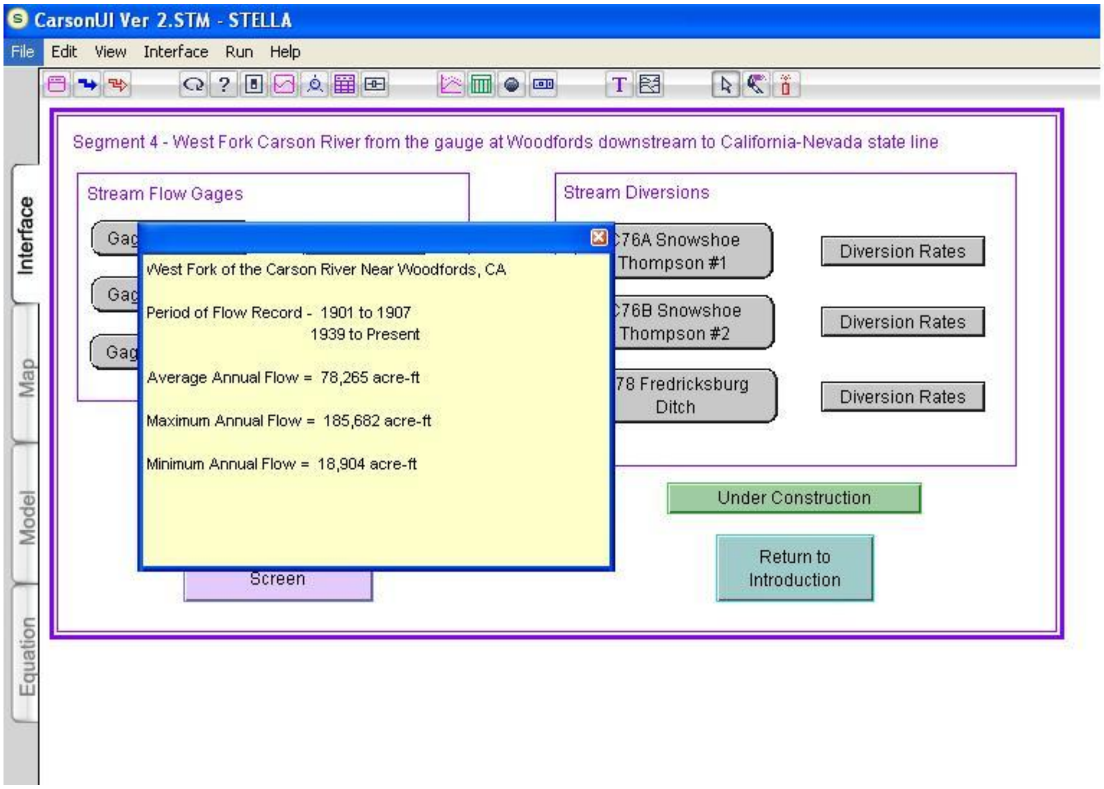


Figure 113. Segment 4 Example for Stream Flow and Diversion Data.



West Fork of the Carson River Near Woodfords, CA

Period of Flow Record - 1901 to 1907
1939 to Present

Average Annual Flow = 78,265 acre-ft

Maximum Annual Flow = 185,682 acre-ft

Minimum Annual Flow = 18,904 acre-ft

Figure 114. Gage 10310000 Example Dialogue Box.

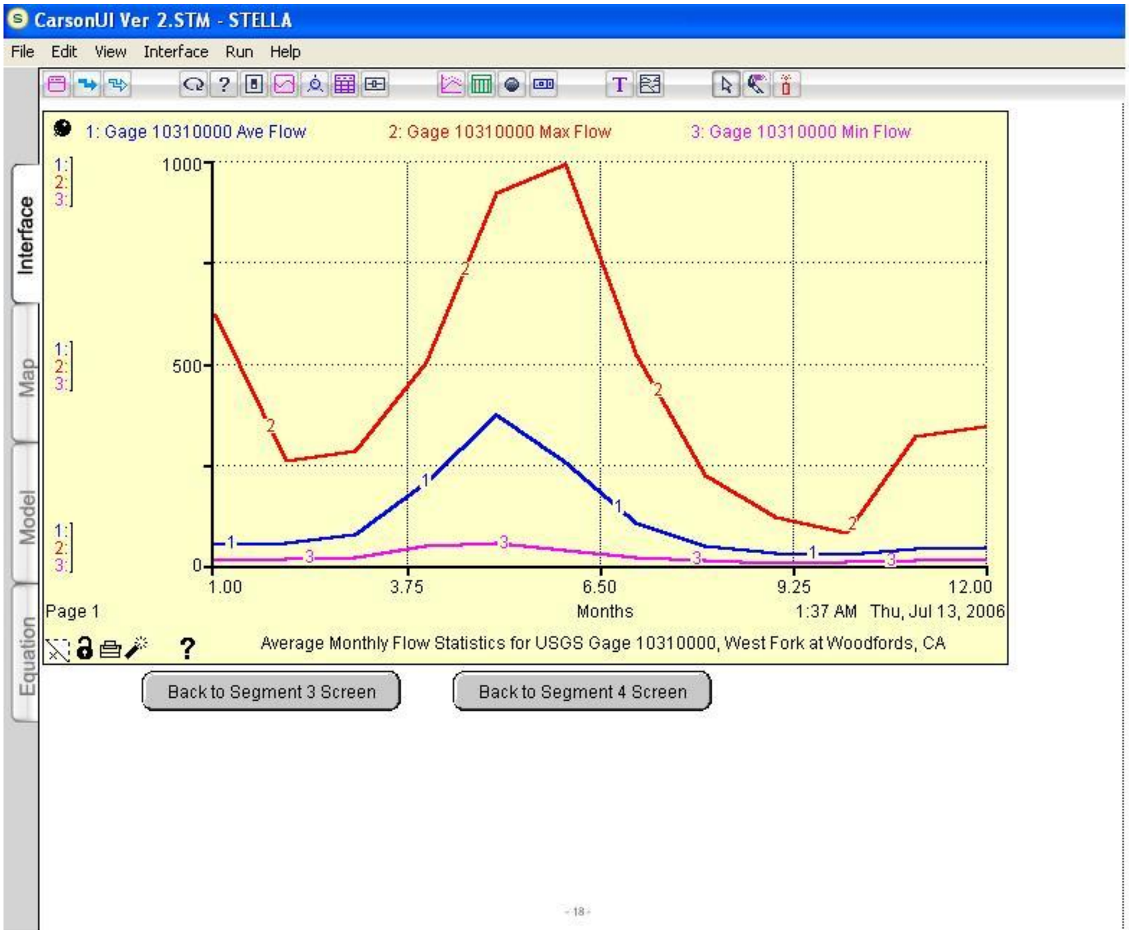


Figure 115. Gage 10310000 Example Graphs.

3.4 Scenario Development and Analysis Element

This portion of the interface provides the user with the ability to establish ‘hypothetical’ water management scenarios within the Carson River watershed and then view the predicted changes in stream flow and diversion characteristics at key locations along the river. The can begin developing a particular scenario by selecting the Scenario Development and Analysis button the Main Navigation screen of the user interface. The user is then take to the Scenario Development and Access screen (Figure 116), at which point the user can begin developing a planning scenario.

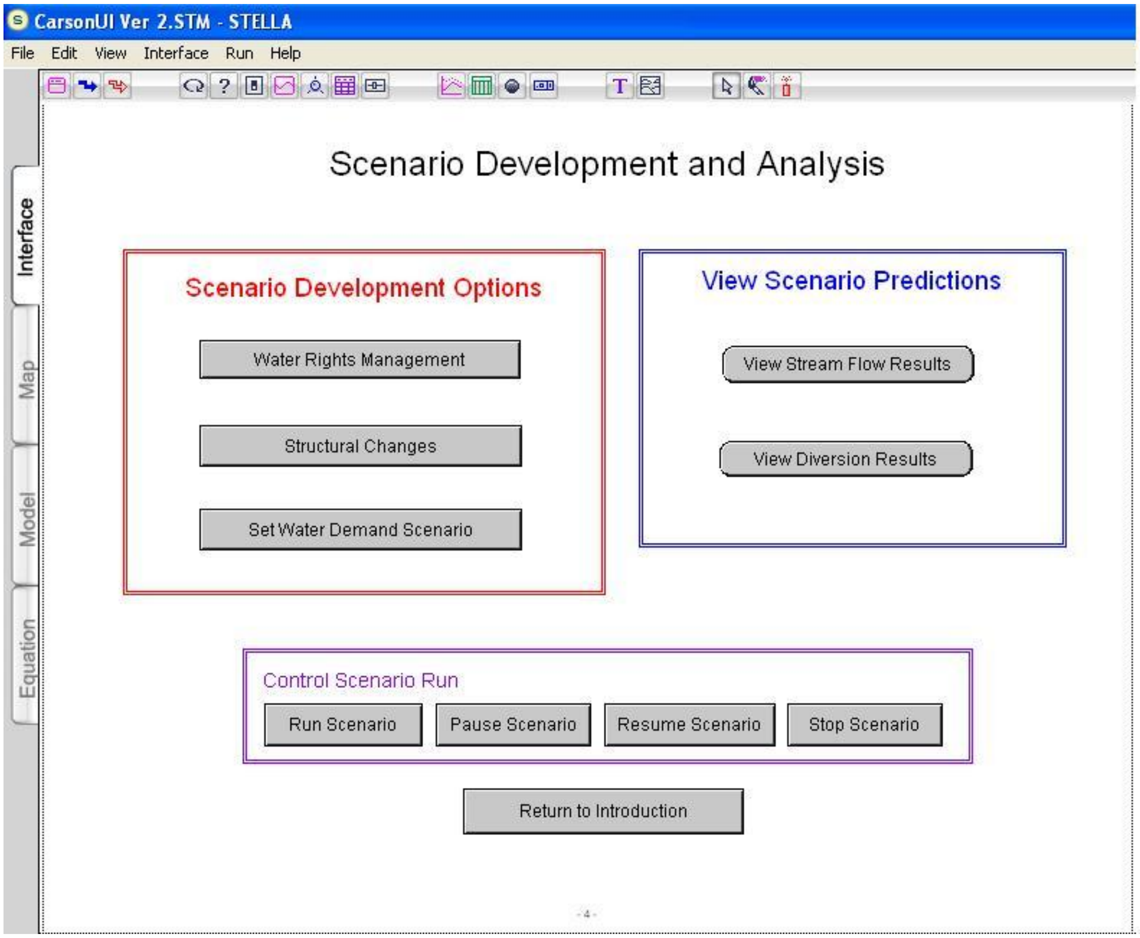


Figure 116. Scenario Development and Analysis Screen.

3.4.1 Scenario Development Options

Within the interface, there are three main elements that are used to develop a scenario, these being: (1) changes to water management within the watershed, referred to as the Water Rights Management option; (2) changes to the structural elements that are used to manage water within the watershed, referred to as the Structural Changes option; and (3) factors which affect water availability and use within the watershed but are not directly controllable, referred to as the Exogenous Factors option.

3.4.2 Water Rights Management

If the user selects the Water Rights Management option, they are taken to the Water Rights Management Screen. Here the user can develop strategies where water rights are purchased from specific segments of the Carson River for use in increasing flows downstream of that segment. In addition, the user can develop strategies that involve the exchange of existing surface water rights for new ground water rights within specific river segments. Once the user has developed the water rights management component of their scenario, they can return to the Scenario Development and Analysis screen by selecting the back arrow button.

3.4.3 Structural Changes

If the user selects the Structural Changes button they are taken to the Structural Watershed Changes screen. From this screen, the user can select options to create New Storage within a specific river segment, increase the Water Use Efficiency within specific river segments and create a Water Reuse Facility within river segments where municipal wastewater is available for treatment and release to the Carson River.

New Storage

If the New Storage option is chosen, the user will be taken to a screen where they must input the amount of water rights that will be purchased to fill the new storage facility, in addition to the operating rules governing water releases for the storage facility. The operating rules can either be entered via filling out a table identifying the target releases by month, or via an input device that allows for this information to be entered graphically.

Water Use Efficiency

If the user selects the Water Use Efficiency option, they are taken to the Water Use Efficiency screen. Here they can use input devices to change the water use efficiency (up to +/- 30%) for diversions within each segment of the Carson River.

Water Reuse

If the Water Reuse Option is chosen, the user is taken to the Water Reuse Screen. Here they can specify the capacity of a water reuse facility for each segment within the Carson River. This capacity can either be entered as a constant amount that is invariable from month to month or year to year, or as an amount that varies with time of the year and the climatic condition within the watershed.

Once the user is finished developing the Structural Changes portion of the scenario they can return to the Scenario Development and Analysis Screen by selecting the back arrow button on each screen.

3.4.4 Exogenous Factors

The user can also create scenarios for factors that are outside the control of water resource planners and policy makers within the Carson River watershed by selecting the Exogenous Factors option. By selecting this option the user is taken to the Exogenous Factors screen where they can specify the anticipated growth in watershed population and the anticipated changes in the climate that governs the flow of water at the headwaters of the Carson River.

The user can input the anticipated rate of growth of the watershed population, as well as the location (by river segment) and type (urban, suburban or rural) of growth within the watershed. The default settings for the interface are for a 3% growth rate that is distributed equally amongst river segments 3 through 7, with the growth occurring predominantly in suburban and urban fashion.

The user can also input the anticipated change in average annual temperature within the Carson River watershed and the anticipated change in precipitation. The temperature change is input in terms of degrees Fahrenheit, while the change in precipitation is entered as a percentage change relative to current conditions within the watershed.

Once the user is finished developing the Exogenous Factors portion of the scenario they can return to the Scenario Development and Analysis Screen by selecting the back arrow button on the screen.

3.4.5 Viewing Scenario Results

After completing the development of a planning scenario the user must return to the Scenario Development and Analysis screen to run the scenario. This is done by selecting the Run Scenario button (Figure 116) on this screen. The user then has the option to view the predicted changes to both stream flows and stream diversions in graphical, tabular and statistical form.

3.4.6 Stream Flow Results

To view the predicted impacts that the developed scenario will have on stream flows at representative locations within the Carson River, the user can select the View Stream Flow Results button (Figure 116) on the Scenario Development and Analysis screen. This will take the user to the Predicted Stream Flows screen (Figure 117). This screen provides a sequence of graphs that depicts the flow at stream gages on the Carson River for the predicted flows, the baseline modeled flows and the flows measured at that gage.

This allows the user to have a visual comparison between their developed scenario and the predicted conditions if no changes to water management within the watershed occurred (baseline case). In addition to the visual comparison provided by the graphical representation of stream flows, the user can compare the predicted, baseline and measured flows in a tabular form by selecting the Tabular Data button (Figure 117), or the user can view a comparison of the summary statistics for the predicted and baseline simulations by selecting the View Flow Statistics button (Figure 117). The summary statistics provide a comparison of the flow conditions at representative river reaches for critical flow periods as determined in the report Otis Bay (2004). These comparisons provide a representation of how the hypothetical planning scenario would perform in regards to meeting critical riparian water demands.

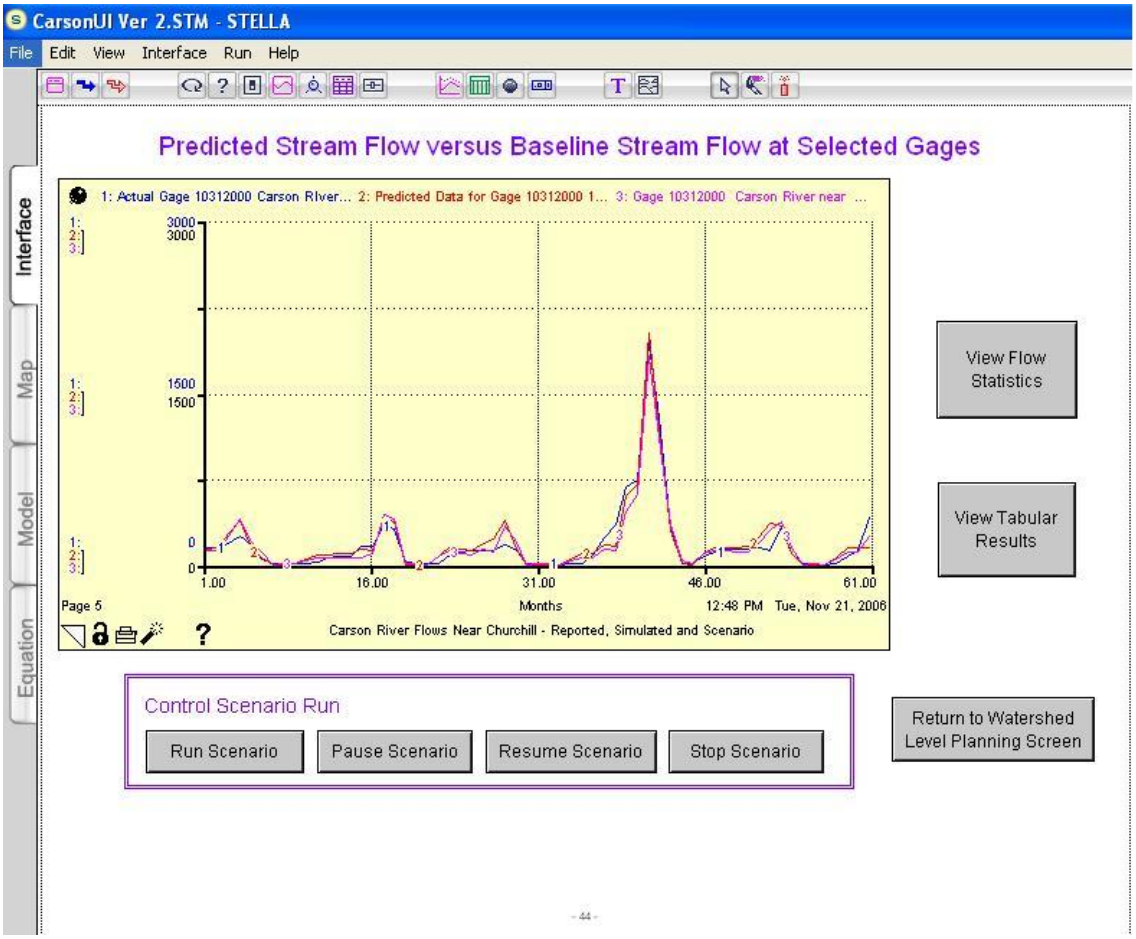


Figure 117. Predicted Stream Flow Screen.

3.4.7 Stream Diversion Results

To view the predicted impacts that the developed scenario will have on stream diversions for each river segment within the Carson River, the user can select the View Diversion Results button (Figure 116) on the Scenario Development and Analysis screen. This will take the user to the Predicted Stream Diversion screen (Figure 118). The screen provides a sequence of graphs that depicts the stream diversions for each segment of the Carson River for the predicted diversions and the measured diversions for that segment. This allows the user to have a visual comparison between the conditions predicted by their developed scenario and the conditions that would be anticipated if no changes occurred within the watershed (baseline case). In addition to the visual comparison provided by the graphical representation of the stream diversions, the user can compare the predicted and baseline diversions in a tabular form by selecting the Tabular Data button (Figure 118), or the user can view a comparison of the summary statistics for the predicted and baseline simulations by selecting the View Diversion Statistics button (Figure 118). These comparisons provide a representation of how the hypothetical planning scenario would perform in regards to meeting diversion demands during dryer hydrologic conditions within the watershed.

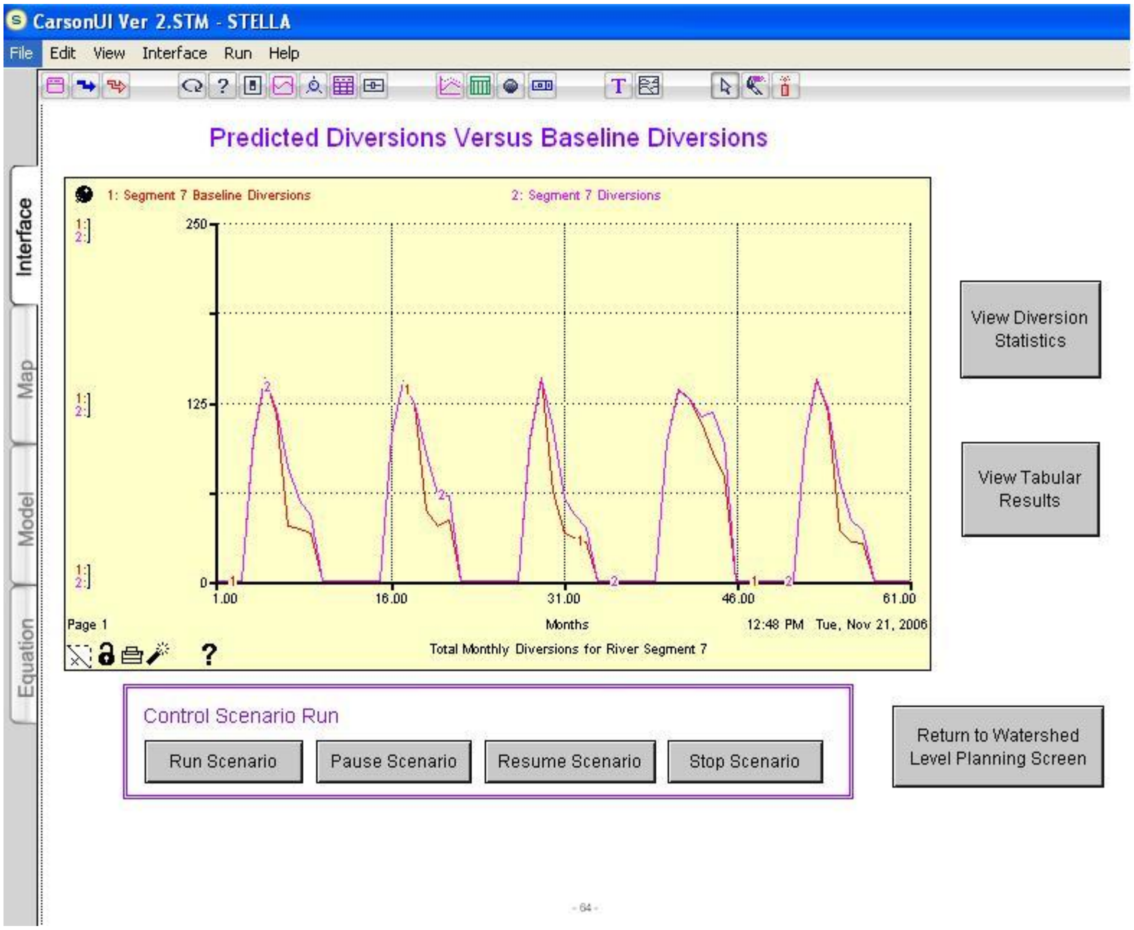


Figure 118. Predicted Stream Diversion Screen.

3.5 Scenario Analysis Example

While Chapter 1 and 2 succeed in individually explaining the possible ramifications of a water right transfer, it is thought that a discussion of a hypothetical model simulated transfer could tie some of these somewhat loose elements together. This will afford the reader a better holistic understanding of what one should consider when transferring water rights. The hypothetical example chosen entails the purchase of all the water rights on Koch Ditch by an environmental group in an effort to transfer that water to Stillwater National Wildlife Refuge (Stillwater NWR). While this specific example is hypothetical, the actual scenario – purchasing upstream water rights for Stillwater NWR – is not. Efforts are underway by the Nature Conservancy, in conjunction with the State of Nevada, the US Fish and Wildlife Service, and the Nevada Waterfowl Association, to purchase an additional 100,000 acre-feet (some 30,000 acre-feet have already been purchased) from upstream users of the Carson River in an effort to sustain a 25,000 acre refuge with 5 acre-feet/acre/year (Nature Conservancy, 2006).

Koch Ditch is located approximately twenty miles west of where the Carson River enters Lahontan Reservoir (Figure 105).

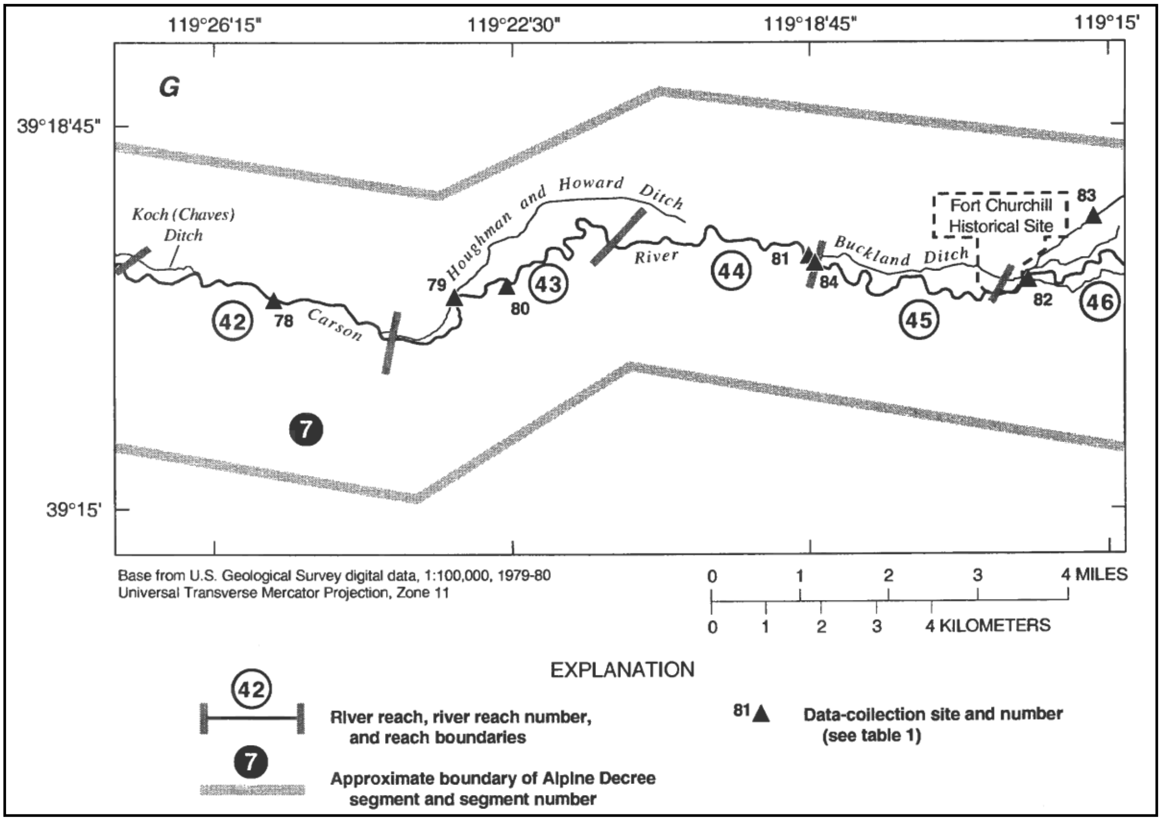


Figure 119. Koch Ditch, Houghman and Howard Ditch, and Buckland Ditch

According to the Alpine Decree, Koch Ditch irrigates approximately 250 acres (*United States v. Alpine Land and Reservoir Company, et al*., 1980). Its average annual withdrawal from the Carson River during the irrigation season amounts to approximately 2,000 acre-feet, or 8 acre-feet/acre (Figure 106). In terms of flow, this would be a constant flow of 5.6 cfs during the irrigation season.

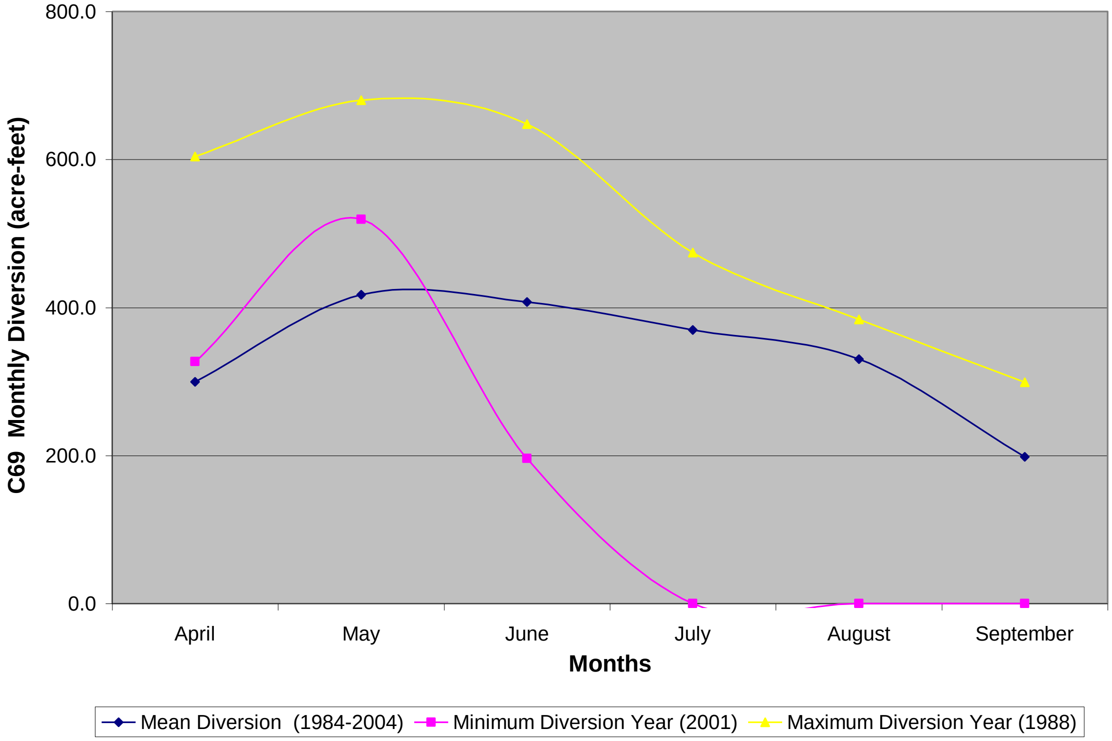


Figure 120. Mean, Minimum, and Maximum Annual Diversions for C69 Koch Ditch (acre-feet)

As was stated above, the goal of the environmental group is to transfer this water to Stillwater NWR. To actually get all of the water there will be difficult, however, as prior to even reaching Lahontan Reservoir, the "new" water must travel by Howard and Houghman Ditch and Buckland Ditch, which respectively pull an annual average of 1,300 acre-feet and 5,500 acre-feet from the Carson River during the irrigation season (Figure 107).

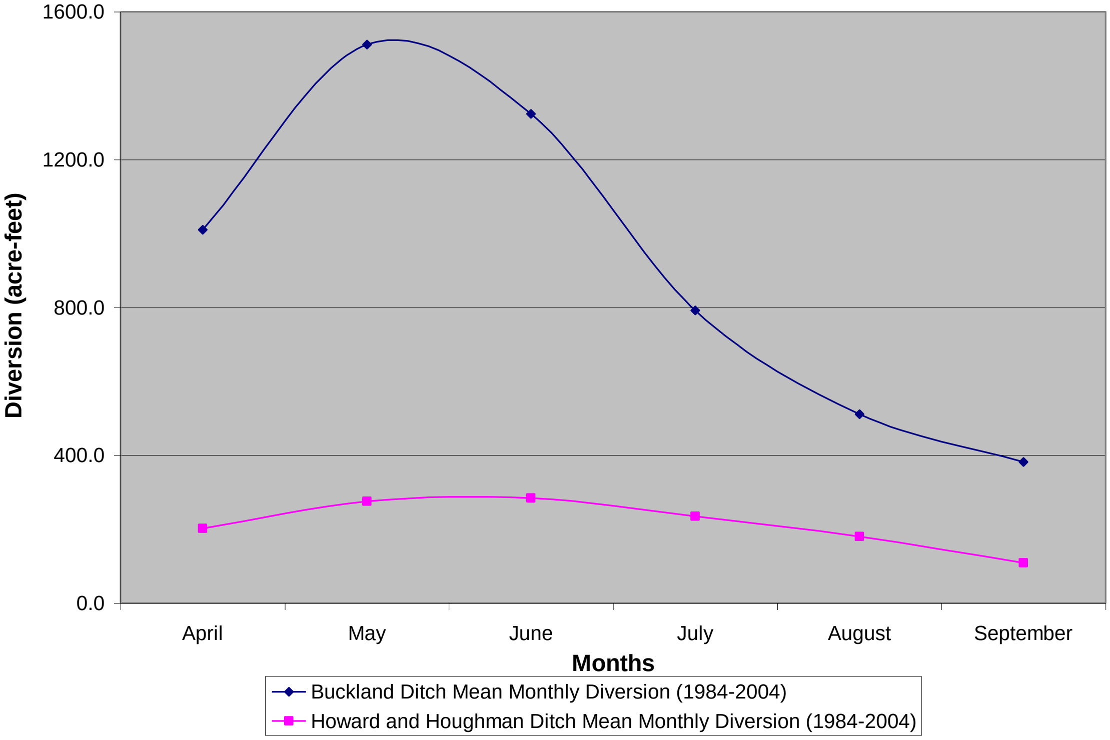


Figure 121 Mean Monthly Diversions of Howard and Houghman Ditch and Buckland Ditch (acre-feet)

The hypothetical transfer was modeled using the traditional years of 1990 to 1999 as this decade richly exhibits the natural fluctuations in precipitation that the Sierras are known for. Predicted changes in flow in the Howard and Houghman Ditch and the Buckland Ditch can be seen in Tables 12 and 13.

Table 12. Hypothetical Increases in Howard and Houghman Ditch Flow (acre-feet) due to Retiring of Koch Ditch Water Rights

	April	May	June	July	August	September	Sum
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	0.0	0.0	0.6	0.0	59.6	60.2
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	0.0	0.6	20.9	11.9	33.4
1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.6	1.8	3.6	6.0
1996	0.0	0.0	0.0	0.6	1.8	3.6	6.0
1997	0.0	0.0	0.0	0.6	94.8	10.1	105.5
1998	0.0	0.0	0.0	1.8	30.2	10.1	42.1
1999	0.0	0.0	0.0	0.6	20.3	10.7	31.6
Average	0.0	0.0	0.0	0.6	17.0	11.0	28.5

Table 13. Hypothetical Increases in Buckland Ditch Flow (acre-feet) due to Retiring of Koch Ditch Water Rights

	April	May	June	July	August	September	Sum
1990	0.0	0.0	23.2	0.0	0.0	0.0	23.2
1991	0.0	0.0	4.2	0.0	0.0	2.4	6.6
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1993	0.0	0.0	1.2	4.3	349.5	195.9	550.9
1994	0.0	0.0	14.9	0.0	0.0	0.0	14.9
1995	0.0	0.0	0.0	0.6	6.8	11.3	18.7
1996	0.0	0.0	0.6	6.2	232.6	174.5	413.8
1997	0.0	0.0	1.8	12.3	321.8	171.5	507.4
1998	0.0	0.0	0.6	1.2	18.5	16.1	36.4
1999	0.0	0.0	1.2	4.9	350.1	188.8	545.0
Average	0.0	0.0	4.8	3.0	127.9	76.0	211.7

As can be seen from the tables above, the new water in the river has little effect on ditch withdrawals in April and May as water supply is not an issue. In July, August, and September, however, when water scarcity becomes more systemic, the two ditches pull significant amounts of this new water out of the system, and prevent it from reaching its destination. This newly diverted water is shown as a percentage of Koch Ditch's actual historic diversions in Table 14.

Table 14. Actual Koch Ditch Diversions, Predicted Increases in Downstream Diversions, and New Diversions as a Percentage of Historic Koch Ditch Diversions

	Actual Koch Ditch Withdrawals (acre-feet)	Predicted New Withdrawals from Howard and Houghman Ditch and Buckland Ditch (acre-feet)	% Lost to Howard and Houghman Ditch and Buckland Ditch
1990	1977	23	1%
1991	2148	67	3%
1992	1763	0	0%
1993	1762	584	33%
1994	1248	15	1%
1995	1327	25	2%
1996	1485	420	28%
1997	2255	613	27%
1998	1648	78	5%
1999	1554	577	37%
average	1717	240	14%

As can be seen from the above, without some sort of agreement, an average of one seventh of the purchased water gets used by downstream users, and in four years, nearly a third of the water never makes it to its destination. And it should be noted that this hypothetical scenario represents somewhat of an ideal situation for the environmental group: only two downstream ditches to worry about prior to Lahontan Reservoir. If the above "trend" was extrapolated, a transfer that passed four ditches could average a loss of nearly 30% and in nearly half of the years, some 60% could be lost without prior agreements and enforcement.

In reality, such an agreement would not be difficult on this stretch of the river, as due to the intermittency of the river's surface flow in a normal irrigation year, this segment is already regulated on a sub-segment scale (*US v. Alpine Land and Reservoir Company et al.*, 1980). Further, for the purposes of this transfer, it may be that it is unimportant what time of year the water gets to Stillwater NWR. If this were the case, it may be that the timing of the full 2,000 acre-foot water right could be amended so that it is sent to Stillwater during a time when low flows are not an issue (during the spring runoff). Of course, it could also be that the summer, notably the late summer, is when Stillwater NWR needs new, fresh water the most, and thus changing the timing would not be desired. This example well illustrates why real people looking to accomplish water rights transfers for Stillwater NWR are looking the hardest at the closest water rights.

In addition to ensuring that the transferred water reaches its final destination, there are other issues to consider. These issues concern the fact that the land that the Koch Ditch formerly irrigated will change dramatically with the transfer. Without a program in place, the fallowed fields could harden and become ripe for erosion – prime conditions for a host of invasive species. Erosion channels and invasive species could both spread to neighboring fields. There is also a habitat issue. While the previous land was focused on producing food for humans, it likely served other creatures as well. A fallowed field full of invasive species does not provide significant habitat benefits. However, if managed properly, the field could be restored to some semblance of its natural condition. New native species on the field could provide valuable new habitat for the native community.

Another issue to consider is the effect the new lack of water will have on the downstream users. While the Koch Ditch does not connect with either the Howard and Houghman Ditch or the Buckland Ditch directly, the loss of water entering the local groundwater table may have an effect on the users of the latter two ditches. It could take years to notice, as groundwater flow can be slow, however, eventually downstream users may notice that they have to put more water in the fields during the late summer. If that happens, it could be that the groundwater tables have locally lowered due to the loss of some 2,000 acre-feet of water that used to get flooded onto the adjacent land.

If the previous situation does arise, it will likely not amount to a successful lawsuit for two reasons. One, there was likely no formal or informal agreement whereby the parties discussed any sort of reliance on groundwater flows. Two, the groundwater table lowering, while real, is systemic and not direct. That is, the loss of the irrigation water lowered the groundwater table for everyone. It would be different if, for example, part of the Howard and Houghman Ditch was supplied by return flow from a ditch that led directly from Koch Ditch. Even then, however, a lawsuit may hinge on what is reasonable reliance or whether a prior agreement was broken. If there was a lawsuit, it would be a torts claim, as a takings claim would not be relevant (no state actor), nor would a Public Trust Doctrine-based lawsuit (no harm to public).

In summary, then, what steps should be taken by someone who desires to successfully transfer water rights in the above hypothetical? The first thing to do would be to model the transfer to determine possible impairment issues. If a model is not available, simply looking at the system as a whole may suffice to tease out the obvious impairment conflicts. For the more complex issues, notably ones that arise from the cumulative effects of various scenarios, the impacts may not be readily apparent, and a model may be necessary. For example, if instead of one transfer, there were multiple transfers occurring, a model would likely be necessary. Even this simple hypothetical could have been far more complicated if only some of the water rights on the Koch Ditch were transferred. Without the total transfer of a ditch, issues such as how much water to leave in the ditch, who pays for the increased transaction costs et al. are ripe. Avoiding such thorny issues is certainly a good argument for retiring an entire ditch.

Secondly, all stakeholders should be invited to a (facilitated) forum to discuss the possible transfer. Plans for mitigating the effects of the transfer would need to be discussed, and agreements would need to be ironed out. Thirdly, a plan to mitigate the effects of fallowing would need to be drafted and agreed upon. The plan would need to have a short-term and a long-term component to it. Short term - to make the transition to natural or an otherwise sustainable state and long-term – to ensure the land stays that way.

The above are only general recommendations. Each transfer will be unique. As such, each transfer will have its own issues. As transfers become more popular, the issues associated with them will likely become more complicated. A key component to determining what these issues are and appropriately dealing with them is having an adequate amount of data. While models can extrapolate poor data sets, nothing beats the real thing.

4. Summary and Recommendations

4.1 Summary

It is not the purpose of this study to provide any planning or policy recommendations for Water Resources Management within the Carson River watershed. Rather, the purpose of this study was to provide a tool that can be used by planning and policy bodies to help them develop robust strategies to ensure sustainable water resource management of the Carson River in the future. None the less, one element that has become a limiting factor in developing this water resources planning tool was the availability of water resources data within the watershed. Thus, one recommendation that specifically addresses this issue is discussed below.

4.2 Recommendations for Increasing Water Resources Data

It has been said that all models are wrong and some are useful. In the context of the Carson River, the creation of a useful model that mimicked the system and produced accurate results was an arduous task for a variety of reasons. First, as with many models, there exists the problem of an inadequate amount of data. While some of the larger diversions have been gaged for significant periods of record, more gages than not have sparse records – often only a few years. And often these periods represent years of heavy or light precipitation, and thus what a "normal" data set may resemble for the particular gage in question was difficult to ascertain.

Secondly, while some gaged diversions and gaged portions of the river may interact with each other such that a correlative relationship exists, the years of record often did not neatly overlap for the portions in question. Thus, new data sets had to be extrapolated from other relationships to successfully correlate the disparate years of record. These data sets were often limited by their own inadequacies.

Thirdly, less than half of the many ditches and sloughs are gaged. In the ungaged cases, flow estimates could only be based on hearsay and/or correlating water rights issued by the governing Alpine Decree to flow.

Fourthly, the use of historical data, while for many models an appropriate method of drawing conclusions, was for this model somewhat problematic in that the historical flow in a few of the ditches had been recently altered. As was discussed above, many of the ditches rely heavily, or in some cases entirely, on return flow from other ditches rather than from an actual physical diversion. In some cases ditches are no longer used. In others, the point of diversion has changed. So the problem exists whereby there was not enough accurate fresh data to build certain relationships, and the use of somewhat questionable historical data occasionally infused the model with relationships that in the current setting, no longer really exist.

Lastly, a very significant portion of the system, return flow, is completely ungaged. Not even hearsay can solve this problem, as often the predominant method for return flow is groundwater. While everyone familiar with the Upper Carson River Basin would agree groundwater flow plays a major role in the system, estimates for actual groundwater return flow would likely vary widely. Admittedly, attaining data on the quantity of groundwater return flow would be difficult. However, determining surface water return flow would only require the addition of another gage at that portion of the ditch that flows back into the river. Based on the surface return flow, estimates of groundwater return flow could be calculated.

The above can and should give the reader cause for viewing the current model with a healthy dose of skepticism. This framework model, Phase I of the Carson modeling project, does make a significant amount of assumptions. However, assumptions are necessary for any model, notably this one given the complexity of the Upper Carson River Basin irrigation ditch system, the lack of data, the governing law, the way the river is managed by watermasters, and the capacity of individual water rights holders to make their own independent decisions that critically affect how much water ends up downstream. Of the above factors, there is one factor that can be readily changed, and changed relatively easily: the lack of data. An increase in data would directly correlate to a decrease in the range of assumptions made in the model. While an historic record would not be created immediately, and thus would not aid this specific model, every year that a gage is not fixed or a necessary gage is not installed, a future modeler who is attempting to aid decision makers will be forced to use a less reliable historic record in constructing his/her model. Of course, any model will always have assumptions and more than likely, modelers will likely always complain of a lack of data. That being said, here, to be clear, there is definitely a lack of data.

Given the complexity of the system being modeled here and the possible ramifications of some of the decisions being contemplated, it should be the goal of decision makers to provide researchers, people that are attempting to aid the decision makers, with the best tools available. The best and easiest way to do this is by gathering more data. The sooner this occurs, the better, as changes to the system are ongoing. Building a larger data set now will aid in understanding not only future changes, but current ones. Obviously acquiring more data costs money and requires political will. It is recognized that possibly very few of the following recommendations will actually be followed. Thus, the recommendations below are given in terms of perceived priority, with the most critical recommendations listed first.

If an in depth understanding of the Upper Carson River Basin is desired, the first priority should be getting every ditch gaged. It would be best to start with those ungaged ditches that carry the most water, as they are most influential to the system. Accordingly, then the following ditches should be gaged or monitored:

Table 15. Ditches That Need Gaging

Ditch Name	Priority
Falke Tilman Ditch	1
Homestream Slough	2
Williams Slough	3
Company Ditch	4
Heimsoth Ditch	5
St. Louis Straight	6
Martin Slough	7

Deluchi Ditches #1 and #2	8
Johnson Ditch	9
Jones East Ditch	10
McCollum Ditch	11
Middle Ditch	12
Park and Bull Ditch	13
Poleline Ditch	14
Thran Ditch	15
Dressler Ditch	16
Whyatt Ditch	17
East Ditch	18
Big Ditch	19
Big Slough	20

Table 15 lists ditches and sloughs that are not gaged or monitored. There are also some river and tributary gages that are recently no longer gaged or monitored. They should be brought back on line, with priority given to the river gages as they provide valuable year round flow data. These gages include:

Table 16. River and Tributary Gages that Need to Brought Back On Line

Gage Number	Location	Type of Flow	Period of Record Stopped In
10309100	E. Fork Carson at Minden, NV	River	1998
10310402	E. Branch Brockliss Slough at Muller Lane near Minden, NV	River	1998
10310403	W. Branch Brockliss Slough at Muller Lane near Minden, NV	River	1999
10309035	Indian Creek SE of Dresslerville, NV	E. Fork Tributary	1998
10309050	Pine Nut Creek SE of Gardnerville, NV	E. Fork Tributary	1997
10309070	Buckeye Creek E of Minden, NV	E. Fork Tributary	1997

10310300	Fredricksburg Canyon Creek near Fredricksburg, CA	W. Fork Tributary	2001

In addition to the above problem gages, the West Fork gage/rating curve at Dressler Lane (C79) periodically does not work correctly, as it sometimes gives false flow readings. This issue should be fixed and the gage monitored year round rather than only during the irrigation season. A similar year round recording issue exists with the Brockliss Slough gages (C80 at Ruhenstroth Dam and C81 at Scossa Box). Both of these “diversions” flow year round yet are only monitored during the irrigation season. Increasing the monitoring at these gages beyond the irrigation season would aid in understanding overall system dynamics. The Ambrosetti Pond gage, while it seemingly functions correctly, has an issue with completeness. Over half of the years that records exist for the gage are incomplete. This issue should be resolved.

There is also an issue with regard to the recording of diversion data during March and October. Most of the upstream diversions now record flows in March and October, though sporadically, while nearly all of the more downstream diversions are only monitored from April through September. For completeness and a more accurate big picture of the system, it would be helpful if all of the diversion gages were consistently monitored from March through October, with values of 0.0 recorded when there is no flow, as opposed to the record being left blank.

There are a few ditches that connect the East Fork to the West Fork. Some of these ditches are gaged, some are not. First of all, all the ditches should be gaged. Secondly, if gages were set at the East Fork at the beginning of these ditches, and at the end of these ditches, near where the ditches enter the West Fork, a much better understanding of the East Fork – West Fork connection prior to the confluence could be gained. In order of priority, these ditches include the Rocky Slough, the Homestream Slough, the Edna Ditch, the Henningson Ditch, and the St. Louis Straight Ditch.

Along the same vein as above, there are a few ditches that are significantly longer than most of the other ditches, yet these ditches only have one gage location, typically at the beginning of the ditch. It would be helpful to have another additional gage (or more) along some of the longer ditches. In order of priority, these ditches include the Allerman Canal, the Fredricksburg Ditch, the Heyburn Ditch, the Virginia Ditch, and the William Slough.

REFERENCES

Alpine County Resource Conservation District and Carson Valley Conservation District (ACRC and CVCD). 1996. *Upper Carson River Water Management Plan*. Gardnerville, Nevada.

Arkansas v. McIlroy, 268 Ark. 227 (1980).

Arnold v. Mundy, 6 N.J.L. 1 (1821).

Black's Law Dictionary, 7th Edition. 1999. Garner, B. Editor in Chief.

California Department of Water Resources (CDWR). 1991. *Carson River Atlas*. Sacramento, California.

Canter, L. et al. 2001. *Valuing Ground Water: Economic Concepts and Approaches,* National Research Council, National Academy Press, Washington, D.C.

Carson Water Subconservancy District (CWSD). *CWSD Current Projects.* Retrieved November 14, 2005, from http://www.cwsd.org/current.html.

Champ, P. et al. (editors). 2003. A Primer on Nonmarket Good Valuation. Kluwer Academic Publishers, Boston, MA.

Coker, A. and Richards, C. (editors). 1992. *Valuing the Environment: Economic Approaches to Environmental Evaluation*. CRC Press, Boca Raton, Florida.

Commonwealth v. Alger, 61 Mass. 53 (1851).

Cosens, B. 2003. *Water Dispute Resolution in the West: Process Elements for the Modern Era in Basin-Wide Problem Solving.* San Francisco State University Law Review. San Francisco State.

Danberg, G. 1975. *Conflict on the Carson*. Carson Valley Historical Society, Minden, Nevada.

Douglas County Master Plan. Retrieved October 15, 2005, from http://cocode.co.douglas.nv.us/mpchapter4.htm.

Drayton, W. 1970. *The Public Trust in Tidal Areas: A Sometime Submerged Traditional Doctrine*. 79 Yale L.J. 762.

Environmental Protection Agency (EPA). 1990. *Carson River Mercury Superfund Site, EPA ID# NVD980813646*. Region 9, San Francisco, CA.

Fadali, E. and Shaw, W. 1997. *Can Recreation Values for a Lake Constitute a Market for Banked Agricultural Water?* Contemporary Economic Policy, Vol. XVI.

Google Images. *Map of Carson River, Nevada*. Retrieved October 15, 2005, from http://130.166.124.2/panoramas/nevada/carson_river_nv_60k.jpg.

Gould, G. 1989. *New Challenges to Western Water Law.* Natural Resources Journal. University of the Pacific, McGeorge, School of Law.

Grant, D. 1995. *Western Water Rights and The Public Trust Doctrine: Some Realism About The Takings Issue*. 27 AZ State L.J. 423.

Hess, G.W., Taylor, R.L. 1999. River-*Operations Model for Upper Carson River Basin, California and Nevada*. U.S. Geological Survey, Water-Resources Investigations Report 98-4240.

Horton, G. 1995a. *Nevada Socioeconomic Overviews*. Nevada Division of Water Resources, Department of Conservation and Natural Resources. Retrieved October 25, 2005, from http://water.nv.gov/Water%20Planning/overview/dg_over.htm

Horton, G. 1995b. *Water Words Dictionary*. Nevada Division of Water Resources, Department of Conservation and Natural Resources. Retrieved October 26, 2005, from http://water.nv.gov/Water%20planning/dict-1/ww-index.htm.

Horton, G. 1997a. *A Chronological History of Lake Tahoe and the Truckee River and Related Water Issues*. Carson City, Nevada: Nevada Division of Water Planning.

Horton, G. 1997b. *Carson River Chronology: A Chronological History of the Carson River and Related Water Issues.* Carson City, Nevada: Nevada Division of Water Planning.

Houghton, S. 1994. *A Trace of Desert Waters: The Great Basin Story.* Reno, Nevada: University of Nevada Press.

Huszar, E. and Shaw, W. 1999. *Economic Values of Mine Dewatering in Northern Nevada* (MS thesis). University of Nevada, Reno.

Illinois Central Railroad Co. v. Illinois, 146 U.S. 387 (1892).

Kennedy/Jenks/Chilton. 1988. *Carson River Management Program, Volume II: Technical Memoranda*. Carson City, Nevada.

Kennedy/Jenks/Chilton. 1998. *Water Resource Analysis of the Upper Carson River Basin*, K/J Job #877029.20. Carson City, Nevada.

Kennedy/Jenks Consultants. 1991. *Upper Carson River Modsim River Model*, K/J Job #877029.07.

Loretto v. Teleprompter Manhattan CATV Corp., 458 U.S. 419 (1982)

Lucas v. South Carolina Coastal Council, 112 S. Ct. 2886 (1992).

Matthew v. Bay Head Improvement Association, 471 A.2d 355 (1984).

Maurer, D. 1986. *Geohydrology and Simulated Response to Groundwater Pumpage in Carson Valley, a River Dominated Basin in Douglas County, Nevada and Alpine County, California*. United States Geological Survey Water Resources Investigation Report 86-4328.

Maurer, D.K. and Peltz, L.A. 1994. *Potential for, and Possible Effects of, Artificial Recharge in Carson Valley, Douglas County, Nevada*. United States Geological Survey with Douglas County Utility Division, Water Resources Investigation Report. Carson City, Nevada.

Maurer, D. et al. 2004. *Updated Computations and Estimates of Streamflows Tributary to Carson Valley, Douglas County, Nevada and Alpine County, California, 1990-2002*. United States Geological Survey Scientific Investigations Report 2004-5179.

Mineral County v. State of Nevada, Department of Conservation, 117 Nev. Adv. Op. No. 23 (2001).

Montana v. United States, 450 U.S. 544 (1981).

National Audubon Society v. Superior Court, 658 P.2d. 709 (1983).

National Weather Service. *Monthly Precipitation Report for the Carson River Basin*. Retrieved October 11, 2005, from http://www.wrh.noaa.gov/rev/hydrology/-monthly_precip.php#carsonriver.

Nature Conservancy. *Places we Protect.* Retrieved November 2, 2005, from http://nature.org/wherewework/northamerica/states/nevada/preserves/.

Nature Conservancy. *Stillwater and Carson Lake Wetlands.* Retrieved April 14, 2006, from http://www.nature.org/wherewework/northamerica/states/nevada/preserves/-art11311.html.

Neuman, J. 2004. *The Good, the Bad, and the Ugly: The First Ten Years of the Oregon Water Trust.* Nebraska Law Review. University of Nebraska.

Nevada Bureau of Mines and Geology. *Map of the Humboldt River System*. Retrieved October 12, 2005, from http://www.nbmg.unr.edu/dox/e32/w.pdf.

Nevada Division of Water Resources (NDWR), Department of Conservation and Natural Resources. 1996. *Nevada State Water Plan*. Retrieved August 28, 2005 from http://water.nv.gov/Water%20planning/wat-plan/con-main.htm.

Otis Bay, Inc. 2004. *Assessment and Recommendations of the Middle Carson River for the Purpose of Recovering and Sustaining the Riverine Ecosystem.*
Otis Bay, Inc. 9225 Cordoba Blvd. Sparks, NV 89436, Draft Report, May 2004. 288 pps.

Penn Central v. City of New York, 438 U.S. 104 (1978).

Quick, J. 1994. *The Public Trust Doctrine in Wisconsin.* Wis. Env. L. J., Vol. 1, No. 1.

Ralph, A. 2003. *Drain the Water and Pull the Plug on the Economy of One Community so that Another Community Can Brim Over With Economic Development: Is it any of the State Water Resource Control Board's Business?* McGeorge Law Review. University of the Pacific, McGeorge School of Law.

Sax, J. et al. 2000. *Legal Control of Water Resources*. West Group Publishing, St. Paul, Minnesota.

Scodari, P. 1990. *Wetlands Protection: The Role of Economics*, Environmental Law Institute, Washington, D.C.

Selvin, M. 1980. *The Public Trust Doctrine in American Law and Economic Policy,* Wis. L. Rev. 6:1403.

Shively v. Bolby, 152 U.S. 1 (1894).

Smith, L. 1950. *The Great Pond Ordinance, Collectivism in Northern New England*. 30 B.U.L. Rev. 178.

State v. Bunkowski, 503 P.2d 1231 (Nev. 1972).

State ex rel. Thornton v. Hay, 462 P.2d 671 (1969).

Truckee-Carson Irrigation District (TCID). 2005. Map retrieved October 17, 2005, from http://www.tcid.org/map.htm.

United Plainsmen Association v. North Dakota State Water Conservation Commission, 247 N.W.2d 457 (N.D. 1976).

United States Bureau of Reclamation, United States Department of the Interior, 1990. *Initial Bench and Bottom Land Map and Criteria, Newlands Project, Nevada*. Sacramento, California.

United States v. California, 332 U.S. 19 (1947).

United States v. Alpine Land and Reservoir Company, et al., 503 F.Supp. 877 (1980).

United States Geological Survey (USGS). *Surface Water Data for the Nation*. Retrieved various dates, from http://waterdata.usgs.gov/nwis/sw.

U.S. Department of Agriculture. *2002 Census of Agriculture, Nevada, County Summary Highlight.* Retrieved November 14, 2005, from http://www.nass.usda.gov/census.

Vaughn v. Vermilion Corp., 444 U.S. 206 (1979).

Wisconsin Department of Natural Resources (WI DNR), Bureau of Water Regulation and Zoning. 1995. *Champions of the Public Trust, A History of Water Use in Wisconsin.*

Appendix A: West Fork Historical Data

YEAR	Monthly mean streamflow, in ft^3/s for 10310000 (W. Fork Headwaters)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1900										39	48.3	52.5	
1901	50.7	111	170	234	473	287	136	76.5	42.8	49.5	56	80.6	106,766
1902	107	238	141	175	286	319	118	38.6	32	33.5	45.9	57.7	95,321
1903	47.9	63.1	63	170	390	353	109	42.6	30.2	31.1	62.4	66	86,228
1904	53.7	114	170	305	647	371	160	74.5	67.1	78.7	64.7	64.4	131,156
1905	90.2	101	125	198	272	189	77.2	29	23.5	31.3	34.2	56.6	73,963
1906	71.8	65.5	65.7	235	924	689	324	155	50.4	52.6	76.9	57.4	167,682
1907	78.8	139	211	502	841	664	525	223	107				
1938										38	30.2	22	
1939	20	22	49.6	211	130	62.2	28.2	16.8	18	24.6	20.1	21.2	37,602
1940	38.4	37.6	94.5	279	445	179	63	35.1	19.3	22.4	23.8	23.3	76,282
1941	25	29	50.5	124	556	247	93.5	59.4	24.9	29.7	34.4	75.5	81,916
1942	66.4	63.9	69.9	222	480	458	158	58.9	34.6	25.1	44.9	55.5	104,931
1943	60.5	61.1	91.3	381	383	222	89.1	47.2	32.7	23.6	23.9	21.9	86,706
1944	22.3	22.3	29.5	76.4	317	137	53.2	25.5	18.7	16.8	32.9	28.1	47,284
1945	27.5	71.4	48	220	432	241	83.5	40.6	26.3	32.6	44.5	48	79,402
1946	61.2	43.3	71.8	305	376	161	60.8	33.1	23.2	23.8	26.9	26.6	73,286
1947	21.9	30.6	62.4	198	260	82.4	40.4	16.3	11.5	22.1	21.7	18.1	47,489
1948	27.9	21.7	24.4	123	314	238	63.9	32	15.7	15.2	17.7	16.2	55,025
1949	15	16.9	19.9	217	324	128	40.6	22.1	16	16.1	19	16.6	51,485
1950	26.4	31.4	45.5	250	439	282	79.8	44	27.1	28.1	321	347	116,205
1951	99.5	105	86.9	178	219	142	49.1	37.3	23.9	23.7	28.8	27.9	61,422
1952	27.1	32.3	36.6	277	778	494	233	86.5	57.8	33.4	30.3	29.6	128,189
1953	47.2	39.3	47.1	251	277	310	138	55.9	34.8	28	30.4	26.7	77,561
1954	23.2	26	65.7	258	258	80.2	40.8	22.6	15.1	15.6	19.1	20.1	51,028
1955	21.3	23.2	29.8	90	300	199	51	25.7	18.3	16.6	19.8	205	60,683
1956	135	74.6	96.5	278	517	427	169	68.2	46.3	38.7	38.3	34.6	116,245
1957	28.4	47	65.5	184	327	251	67	33	20.1	20.8	23.9	24.3	65,916
1958	20.9	28.7	34	129	741	386	128	50.8	35.2	23.9	27.5	23.6	98,824
1959	36.9	31.3	61.7	188	145	84.4	35.3	14.9	16.2	17.4	17	16.1	40,048
1960	16.5	24.7	62.2	187	143	91.6	34.9	15.6	7.03	11.1	15.2	14	37,553
1961	13.7	23.6	29.9	123	138	76	31	20	14.9	16.2	13.5	13.7	30,983
1962	15.1	18.8	20	272	324	225	64.3	35.9	27.1	42.6	27.2	30.3	66,573
1963	79.1	259	57	100	363	356	115	64.3	36.9	30.7	65.5	36	93,427
1964	33.9	30.4	40.5	158	223	129	38.9	22.2	12.4	13.1	20.1	232	57,815
1965	109	84.2	103	289	467	364	148	92.9	56.5	30.4	42	37.8	110,151
1966	36.1	32.6	75.7	253	242	76.9	42.7	25.7	12.2	14.2	29.5	44.6	53,499
1967	33.2	42.5	74.1	53.9	431	531	271	63.5	51.4	47.3	39.2	28.5	100,884
1968	32.4	84.9	82.2	216	242	123	45.3	39.5	14.3	21.8	41.9	31.5	58,650
1969	37.3	40.4	44.5	256	791	494	178	74.5	42.6	37	33.2	53.2	126,122
1970	140	94.5	110	186	365	262	102	55.6	28.5	23.5	33.4	36.2	86,767
1971	62.1	65.3	74.5	213	346	332	137	48.8	35	29.5	34.5	30.8	84,999
1972	31.2	33.9	153	157	250	156	53	31.5	25.4	31.2	29.8	53.5	60,895
1973	49.5	39.4	44.5	186	462	216	64.8	44	31.3	25.6	111	63.5	80,933
1974	121	57.3	88.5	207	478	274	117	65.7	40.2	22.3	25.5	23.6	92,043
1975	27.1	27.1	37.4	46.6	476	439	137	51.4	32	42.2	43.3	30.2	84,152
1976	26.3	26.3	43.9	87.6	122	48.7	22.7	20.4	16.7	16.3	16.6	14	27,884
1977	14.1	16.3	18.2	65.4	56.4	60.3	18.1	11.1	7	10.4	15.6	20.9	18,904

YEAR	Monthly mean streamflow, in ft^3/s for 10310000 (W. Fork Headwaters) cont.												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1978	20.5	24.4	65.3	151	364	304	119	48.6	42.3	18.3	22.3	19.8	72,580
1979	44.9	31.2	64.5	165	390	177	59	38.9	21	18.1	21.6	17.1	63,510
1980	116	76.2	64.5	258	469	325	189	59	39.2	25.8	22.9	23.8	100,854
1981	23.1	41.4	46.9	197	191	78.8	34.7	23.8	12.7	18.8	97.1	156	55,638
1982	62.8	176	115	329	595	421	194	56.5	49.9	79.1	88	64.1	134,336
1983	54.3	55.8	80.9	113	619	996	433	213	120	53.6	179	153	185,682
1984	101	69.8	116	258	543	281	104	50.5	38.7	34.3	45.3	46.1	102,123
1985	41.3	40.6	48.2	273	243	113	44.8	36.4	33.1	23.3	24.1	32.3	57,484
1986	54.1	156	283	390	482	350	121	58.6	43.3	30.8	27.1	26.9	121,843
1987	27.9	33.5	44.8	146	142	55	34.4	24.3	15.9	16.1	19.7	25.6	35,314
1988	30.7	33.7	50.8	90.5	95.4	64.8	29.3	17.6	9.16	8.27	13.9	17.5	27,831
1989	18.6	19.9	158	326	229	148	45.3	35.6	30.7	23.2	22	19.5	64,986
1990	20.6	19.9	62.5	171	114	70.5	27.2	24.2	22.9	12.8	13.1	12.8	34,472
1991	15.5	17.1	29.4	107	238	136	35.5	20.4	15.3	15.2	21.2	19.1	40,523
1992	18.8	23.7	49	142	93.3	37.4	24.8	15.3	11.6	10	16.8	18.4	27,799
1993	21.9	25.6	90.7	268	575	313	129	47.6	34.7	25.1	21.3	22.9	95,416
1994	24.2	20.9	40.7	105	113	48.6	22.3	13.3	12	16.5	23.9	22.9	27,987
1995	37.4	60.4	160	241	743	738	426	132	53.7	33.4	30.6	50.2	163,901
1996	49	133	121	315	549	260	92.3	40.9	31.3	26.4	52.6	78.6	105,451
1997	621	109	188	335	399	219	79.2	39.1	30.5	27.2	26.9	26.5	127,289
1998	40.3	46	133	214	427	591	244	63.1	46.9	33.6	36.9	37.8	115,628
1999	35.7	44.1	60	160	574	353	105	50.2	34.6	26.2	29.7	26.2	90,745
2000	29.5	37	65.4	260	313	134	39.2	30.3	23.5	21.4	20.5	20.2	60,031
2001	20.9	22.3	53.7	121	207	43	21.5	16.5	12.7	12.4	19.4	22.6	34,711
2002	29.2	30.9	53.3	280	252	128	34.3	19.5	15	16.7	37.4	21.9	55,362
2003	31.8	35.9	73.1	127	369	265	49.6	25.7	19.6	20.8	21.3	26.3	64,419
2004	23.4	23.3	109	221	210	96.5	30.3	18.7	15.2				
Mean	53	56	78	207	374	256	104	47	30	27	39	46	78,265

YEAR	Monthly mean streamflow, in ft^3/s for 10310300 (Fredricksburg Canyon)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1989	1.18	1.45	2.76	4.22	4.49	3.32	2.44	2.17	2.06	1.75	1.89	2	1,797
1990	1.81	1.95	2.13	2.37	2.25	1.8	1.5	1.45	1.32	1.3	1.58	1.49	1,263
1991	1.25	1.28	1.47	1.73	2.79	2.3	1.49	1.32	1.15	1.43	1.37	1.32	1,142
1992	1.48	1.28	1.35	2.18	1.85	1.14	1.03	1.2	1.3	1.06	1.18	1.54	1,001
1993	1.8	1.5	2.26	2.68	8.6	7.33	4.16	3.16	2.86	2.78	2.59	2.3	2,544
1994	2.04	2.29	2.16	2.45	2.6	1.79	1.68	1.57	1.65	1.4	1.52	1.48	1,363
1995	1.68	1.86	3.25	3.32	7.56	12.7	11.3	7.09	5.02	4.79	4.29	4.21	4,063
1996	3.9	4.22	4.16	4.61	8.12	8.67	6.08	5.06	5.01	4.65	4.73	5.2	3,890
1997	69.7	4.77	6.05	9.65	14	6.55	7.42	3.99	2.65	5.97	5.34	3.82	8,526
1998	3.66	3.5	4.36	5.16	6.97	12.7	10.6	9.46	6.92	5.44	5.74	5.39	4,832
1999	5.02	5.21	5.13	5.9	8.28	8.53	5.95	7.47	6.7	5.2	3.89	3.8	4,290
2000	3.82	4.13	3.93	4.1	4.48	5.09	4.1	3.53	3.51	3.58	3.6	3.37	2,848
2001	2.88	3.03	3.95	3.71	3.19	1.89	1.94	1.88	2.29				
Mean	7.7	2.8	3.3	4.0	5.8	5.7	4.6	3.8	3.3	3.3	3.1	3.0	3,130

YEAR	Monthly mean streamflow, in ft^3/s for 10310402 (Lower Brockliss Slough)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994				8.86	23.8	8.35	1.82	0.67	1.11	1.95	0.54	0.45
1995	4.6	1.81	56.8	10.4	156	211	42.8	12.9	13.3	7.29	1.84	12.4
1996	5.57	14.6	3.07	18.8	133	27.5	10.4	10.6	7.41	7.96	11.4	13.3
1997	189	15.1	19.7	56	61	34.4	15	12.3	10.1	6.64	2.44	1.51
1998	2.19	4.72	34.7	7.64	55.9	88.7	18.3	10.4	10.6			
Mean	50.3	9.06	28.6	20.3	85.9	74	17.7	9.37	8.5	5.96	4.06	6.92

YEAR	Monthly mean streamflow, in ft^3/s for 10310403 (Upper Brockliss Slough)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994						5.74	2.41	0.24	0.47	5.89	24.1	40
1995	96.7	80.3	216	186	404	448	285	52.9	30.5	44.6	56.2	113
1996	130	227	223	337	438	204	66.5	19.9	15.3	40.6	107	197
1997	473	187	204	261	309	174	42.6	21.7	22.5	48.3	62	62.6
1998	82.3	122	175	164	336	435	129	20.2	46.6			
Mean	196	154	205	237	372	253	105	23	23.1	34.8	62.3	103

YEAR	Monthly mean streamflow, in ft^3/s for C76A (Snowshoe Thompson Ditch #1)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		8.5	15.1	17.6	9.6	7.5	3.1		3,708
1985		11.6	16.7	10.9	7.7	5.3	5.9		3,514
1986		12.3	20.1	16.9	11.6	7.8	5.5		4,489
1987		16.9	17.1	8.2	5.5	4.1	3.6		3,351
1988	17.2	15.1	10.0	7.7	4.2	2.7	0.2		3,466
1989		21.0	20.3	13.7	7.6	6.3	4.7		4,449
1990		20.5	19.8	10.9	8.8	6.9	5.6		4,382
1991		7.6	22.9	14.0	8.9	5.6	5.6		3,916
1992		20.5	17.7	8.3	5.1	4.9	4.7		3,698
1993		8.5	18.1	17.1	17.4	7.7	2.7	0.0	4,340
1994		16.3	22.4	9.4	7.0	4.9	6.8		4,049
1995		0.0	2.0	16.8	15.6	12.2	9.7		3,411
1996		8.1	9.1	12.8	12.9	11.5	10.0	0.6	3,934
1998		5.8	15.9	17.6	16.6	6.6	6.9		4,213
1999		5.2	11.5	19.0	15.3	10.1	5.7		4,044
2000		14.1	20.0	19.0	9.9	5.5	5.2	2.3	4,606
2001	6.8	8.4	18.1	8.8	6.6	5.1	4.6	1.7	3,638
2002	0.2	19.8	16.0	14.8	6.3	5.1	5.5	6.3	4,476
2003		8.3	17.7	11.3	5.7	5.0	6.2	2.0	3,404
2004	0.8	10.8	18.5	10.7	5.9	4.8	4.5	0.1	3,399
Mean	6.2	12.0	16.4	13.3	9.4	6.5	5.3	1.9	3,924

YEAR	Monthly mean streamflow, in ft^3/s for C76B (Snowshoe Thompson Ditch #2)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1997	1.5	14.8	18.4	13.5	10.9	3.7	8.8		4,326
1998		9.6	9.8	11.3	20.8	5.5	1.9		3,579
1999		5.3	11.7	9.8	6.0	0.0	0.0		1,991
2000		13.9	11.8	9.2	0.0	0.0	0.0		2,101
2001		6.5	15.6	1.3	0.0	0.0	0.0		1,424
2002		6.5	10.1	9.8	0.0	0.0	0.0		1,587
2003		1.2	14.2	10.7	1.9	0.0	0.0		1,701
2004		7.1	9.5	7.6	0.6	0.0	0.0		1,493
Mean	1.5	8.1	12.6	9.2	5.0	1.2	1.3		2,275

YEAR	Monthly mean streamflow, in ft^3/s for C78 (Fredricksburg Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		23.6	42.8	37.3	25.9	15.2	11.6		9,472
1985		26.0	38.8	26.2	12.0	9.2	9.8		7,378
1986		31.4	42.7	35.9	31.0	21.0	15.5		10,751
1987		24.3	30.5	14.0	9.3	8.9	9.2		5,824
1988		24.6	16.8	12.6	10.8	11.3	10.3	0.7	5,257
1989		29.9	28.8	25.7	18.1	16.1	15.1	0.6	8,114
1990		34.8	33.5	15.9	14.3	14.5	12.0		7,563
1991		16.5	26.8	22.0	16.4	12.1	9.4		6,254
1992		31.1	24.6	16.2	13.2	11.3	4.7		6,109
1993		18.5	34.3	33.3	20.0	17.1	13.8	0.3	8,309
1994		0.0	18.1	13.2	14.3	10.4	4.0		3,648
1995		21.2	28.0	27.4	28.8	29.6	17.5		9,240
1996		24.9	40.5	37.3	23.6	14.8	17.1	7.2	10,010
1997	9.7	36.3	25.2	29.1	22.1	7.9	8.9		8,410
1998		11.2	18.7	28.2	30.3	18.9	19.8	2.9	7,875
1999		17.1	24.9	27.4	23.7	17.2	11.2		7,368
2000	1.5	30.6	29.4	24.7	15.4	12.0	9.5	2.9	7,614
2001	2.5	21.8	28.5	14.0	9.4	8.6	7.8	1.3	5,688
2002	4.2	29.1	27.8	24.4	11.2	7.9	7.1	1.3	6,826
2003	11.2	23.2	36.3	36.0	20.3	12.8	12.2	2.0	9,326
2004	12.0	27.7	29.9	23.4	17.2	11.0	6.7	1.3	7,834
Mean	6.8	24.0	29.8	25.0	18.4	13.7	11.1	2.0	7,565

YEAR	Monthly mean streamflow, in ft^3/s for C79 (W. Fork at Dressler Lane)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		106.9	437.8	157.1	39.1	14.0	2.8		46,057
1985		135.5	82.4	23.4	4.7	2.8	1.0		15,047
1986		317.3	392.0	207.7	20.6	12.0	7.6		57,806
1987		13.5	13.0	10.0	4.2	3.2	2.5		2,807
1988		2.0	11.9	6.8	3.1	1.0	0.8	0.3	1,580
1989		203.9	140.7	53.4	10.8	5.9	6.8	1.1	25,460
1990		35.0	11.6	14.7	15.2	4.2	2.4		5,008
1991		21.7	88.6	41.2	9.0	4.6	3.6		10,241
1992		30.8	11.3	10.5	6.7	5.0	3.6		4,076
1993		0.0	0.0	5.0	40.3	7.1	7.6	1.9	3,783
1994	1.9	7.7	16.9	10.6	5.1	2.6	2.8	3.8	3,124
1995		219.0	831.4	1001.6	417.3	48.6	26.7		153,992
1996		200.5	600.6	128.7	33.0	6.2	5.2	1.1	59,304
1997		188.4	228.3	65.2	5.2	2.4	1.5		29,686
1998		46.9	250.3	460.0	60.7	2.5	2.7	1.8	49,704
1999		41.0	423.3	133.4	5.8	0.8	0.6	0.2	36,871
2000	3.8	39.5	74.8	6.4	1.1	0.9	0.3	0.0	7,714
2001	1.4	6.1	14.2	1.1	0.5	0.1	0.1	0.0	1,430
2004			56.9	25.2	11.7	8.6	6.3	4.8	6,915
Mean	2.4	89.8	194.0	124.3	36.5	7.0	4.5	1.5	27,400

YEAR	Monthly mean streamflow, in ft^3/s for C80 (Brockliss Slough at Ruhenstroth Dam)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		78.4	271.6	111.8	34.8	15.0	3.7		31,296
1985		93.7	51.7	23.8	8.4	7.7	6.5		11,544
1986		217.3	253.7	138.4	28.1	14.2	10.2		39,981
1988		0.6	5.9	3.2	2.6	2.9	2.3	0.2	1,078
1989		121.5	89.6	43.4	7.3	2.9	4.7	0.3	16,244
1990		29.9	9.1	13.8	9.4	3.3	3.0		4,121
1991		18.8	58.1	29.2	5.7	2.9	4.0		7,191
1992		11.4	4.4	4.1	4.0	5.0	4.4		2,006
1993		170.7	408.4	192.8	14.5	0.0	0.0		47,630
1994	1.8	21.4	21.5	18.5	5.5	3.5	3.1	3.9	4,778
1995		144.0	449.4	481.1	237.0	45.0	13.3		82,962
1996		158.8	321.5	125.4	38.4	7.8	4.9	1.5	39,905
1997		196.8	182.5	102.7	29.8	20.7	15.6		33,065
1998		168.7	314.0	378.1	116.9	8.5	11.2	6.3	60,625
1999		140.5	269.2	172.3	41.0	4.9	4.8	4.0	38,512
2000	29.3	115.6	129.9	55.0	12.3	9.3	6.0	0.8	21,672
2001	16.1	42.5	55.9	12.8	4.2	2.3	3.4	4.2	8,585
2002	26.2	113.4	102.1	46.7	13.4	9.6	9.3	3.3	19,593
2003	17.7	65.0	163.8	124.2	12.0	10.2	9.2	1.2	24,405
2004	42.6	51.9	67.3	21.2	8.0	3.9	7.7	7.0	12,729
Mean	22.3	98.1	161.5	104.9	31.7	9.0	6.4	3.0	25,396

YEAR	**Monthly mean streamflow, in ft^3/s for C81 (Brockliss Slough at Scossa Box)**								**Total Acre-Feet**
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		59.1	227.2	82.0	16.1	4.3	1.2		23,688
1985		83.4	46.0	10.1	3.8	1.8	1.8		8,847
1986		179.8	205.3	127.2	13.3	6.9	8.6		32,651
1987		6.6	9.0	6.4	2.7	1.5	1.2		1,659
1988		0.1	0.4	2.4	2.6	0.7	0.2	0.2	399
1989		120.0	83.1	24.9	5.7	3.4	4.4	1.3	14,633
1990		23.7	6.6	10.2	10.8	3.2	1.2		3,356
1991		0.0	35.8	13.9	4.4	2.0	1.7		3,530
1992		15.5	5.1	3.9	2.5	2.1	1.0		1,809
1993		147.2	342.7	160.5	27.8	3.5	1.7		41,406
1994	0.0	4.7	15.4	9.8	3.1	1.2	1.2	3.3	2,358
1995		134.9	383.8	415.6	229.8	28.5	11.9		72,948
1996		181.0	311.4	128.4	40.3	9.4	6.4	1.6	41,093
1997		190.9	226.4	100.0	16.8	7.6	7.9		33,198
1998		78.3	242.8	320.7	100.7	9.9	13.4	11.5	46,979
1999		91.3	296.3	198.3	28.5	8.1	3.6	4.1	38,163
2000	16.8	102.7	133.0	30.1	3.5	2.6	2.9	0.2	17,670
2001	4.4	16.4	46.0	4.6	3.0	1.3	1.6	0.8	4,758
2002	5.9	77.6	66.7	29.9	7.1	4.6	3.9	2.3	11,954
2003	9.0	50.4	148.0	105.9	8.2	9.7	5.2	2.4	20,514
2004	9.0	50.4	148.0	105.9	8.2	9.7	5.2	2.4	20,514
Mean	7.5	76.9	141.9	90.0	25.7	5.8	4.1	2.7	21,054

Appendix B: East Fork Historical Data

YEAR	Monthly mean streamflow, in ft^3/s for 10308200 (E. Fork Headwaters)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1961	56.3	83.9	103	358	556	390	103	53.5	39.7	39.8	42.9	49.8	113,200
1962	51.6	130	137	907	943	1,081	305	117	78.5	94.5	68.9	69.6	239,906
1963	262	710	211	363	1,237	1,267	450	150	121	83.9	200	130	310,717
1964	92.8	97.7	128	375	788	580	164	87.7	47.5	39	61.3	718	192,781
1965	335	252	250	689	1,185	1,285	637	310	185	125	130	132	333,069
1966	119	103	266	676	896	318	125	82.2	48.5	46.4	84	194	179,042
1967	155	187	445	317	1,670	2,175	1,175	292	153	102	84.4	76.4	413,551
1968	128	231	245	448	812	531	154	116	61.3	69.9	126	91	181,589
1969	345	177	288	1,050	2,447	1,825	662	239	146	135	103	158	458,526
1970	542	289	294	393	1,104	988	333	138	91.5	63.9	122	126	270,857
1971	198	209	239	450	926	1,359	517	162	103	84.3	101	130	270,128
1972	101	137	414	363	917	753	178	84.4	63.6	78.6	80.8	100	197,777
1973	142	124	165	570	1,649	955	217	133	94.7	72.2	333	201	281,673
1974	393	204	329	521	1,485	1,259	387	162	91.6	69	78.8	82.7	306,178
1975	91.6	105	191	252	1,340	1,655	528	155	120	138	134	87.8	290,074
1976	76.4	80.2	126	235	488	173	104	59.4	48.1	41.5	32.6	45	91,352
1977	44.2	48.7	58.7	183	197	243	58	33	21.1	24	36.8	78.9	61,862
1978	99.4	117	312	438	1,185	1,389	542	177	134	67.5	77.7	79.7	279,232
1979	172	156	273	509	1,439	803	211	118	71.5	71.5	80.8	80.9	241,242
1980	545	329	264	649	1,456	1,397	863	220	129	93.8	78.5	80.4	368,941
1981	68.9	135	150	486	665	345	86.9	65.9	42.5	58	264	435	169,244
1982	216	734	386	1,121	1,841	1,577	787	268	207	346	329	265	485,860
1983	230	290	483	470	2,135	2,996	1,428	477	239	168	476	463	595,951
1984	309	215	341	572	1,617	1,019	381	153	100	101	134	107	305,556
1985	93.8	112	164	758	871	459	142	92.3	89.8	89.8	83.4	128	186,151
1986	192	917	983	951	1,578	1,413	418	157	116	103	70.5	59.8	417,340
1987	57.9	111	137	477	537	197	89.3	47.8	18	36.2	52.1	65.5	110,129
1988	73.6	85.7	148	278	361	206	80.9	50.6	20.9	26.1	46.5	53.5	86,374
1989	45.5	88.6	457	857	885	743	170	89.9	75	73.1	65.9	67.1	218,430
1990	72	79.3	197	481	396	263	101	62.5	41.1	34	38.8	41.4	109,010
1991	48.5	43.9	110	267	630	573	128	67.9	55.5	57.7	81.8	66.7	128,771
1992	58.1	100	143	460	392	135	76.3	50.7	34.8	35.3	43.5	41.9	94,643
1993	101	101	463	662	1,702	1,237	532	158	93.2	71.4	62.9	63.3	317,941
1994	62.1	64.5	142	383	581	302	88.9	45.8	32.2	43.9	78.7	73.3	114,706
1995	188	229	718	726	1,684	2,601	1,721	459	180	108	86.8	146	535,485
1996	143	505	461	860	1,950	1,344	429	133	94.7	73.6	151	301	388,448
1997	1,722	367	514	826	1,431	946	293	146	97.2	73.7	74.8	86.4	398,376
1998	119	131	387	507	904	1,692	1,033	258	143	106	114	115	333,089
1999	137	238	261	528	1,628	1,535	482	158	93.3	73.9	78.9	71.9	319,117
2000	113	181	222	650	1,203	634	170	92.1	62	59.5	53.2	56	211,099
2001	51.9	61	195	418	943	228	93	54.4	32	31.7	57.7	75.7	135,998
2002	113	111	188	667	879	614	130	66.9	45.8	41.4	95	83.1	183,088
2003	157	151	227	359	1,073	1,112	199	94.4	59.8	41.5	46.2	74.7	217,000
2004	71.1	100	373	564	832	411	107	70.3	39.6				
Mean	191	203	286	547	1124	977	384	141	88	79	108	131	259,151

YEAR	Monthly mean streamflow, in ft^3/s for 10308800 (Bryant Creek)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1962	2.23	5.94	7.04	25.1	11.5	5.04	2.7	2.27	2.18	2.86	2.64	2.64	4,331
1963	12.1	13	6	11	21	17	5.63	3.13	3.27	3.17	4.34	3.54	6,196
1964	3.22	3.06	4.32	6.76	5.57	3.24	2.19	2.08	2.6	2.5	2.88	4.6	2,596
1965	6.04	5.56	5.94	21.3	18.5	6.16	3.18	3.24	3.01	2.93	3.88	3.96	5,045
1966	3.93	3.44	8.66	11.6	6.62	3.94	2.49	2.32	2.59	2.7	3.06	5.51	3,434
1967	5.79	6	23.5	12	52.1	24.5	6.83	4.98	4.93	4.38	4.14	3.6	9,266
1968	3.64	7.23	7.85	8.97	6.77	3.97	2.87	2.71	2.94	2.91	3.23	3.1	3,374
1969	15.4	5.41	20.8	71.8	71.5	26	9.16	5.59	5.05				
1978	4.36	5.99	13	14	13.1	5.39	3.04	2.85	3.04	2.93	3.1	2.52	4,422
1979	4.55	4.66	7.9	9.68	9.49	4.33	2.94	2.68	2.39	2.75	3.09	3.41	3,492
1980	13.3	11.8	9.83	27.2	31.2	8.74	4.53	3.46	3.51				
1995	6.42	7.04	52	29.2	71.1	33.9	7.56	4.33	3.68	4.02	4.09	4.58	13,832
1996	5.04	21.2	29.3	37.6	23.2	6.69	6.25	4.18	3.93	3.75	4.44	10.7	9,379
1997	59.1	14.8	26.7	21.3	10	5.06	4.8	3.69	3.62	4.01	4.49	4.19	9,790
1998	4.55	5.09	26	19.5	33.9	14.3	5.71	3.97	4.42	4.43	4.62	4.37	7,931
1999	4.73	7.62	9.65	23.1	29.2	7.72	3.95	3.72	3.97	3.96	3.79	3.6	6,335
2000	4.23	5.32	6.79	6.71	4.12	3	2.53	2.36	2.56	2.86	3.51	3.51	2,858
2001	3.6	3.36	4.96	5.75	3.46	2.09	1.85	1.82	1.93	2.6	2.81	2.83	2,234
2002	3.52	3.51	4.87	6.7	4.09	2.81	1.9	1.81	2.04	2.37	3.37	3.37	2,431
2003	5.33	4.17	5.48	7	5.63	2.86	1.86	1.79	1.41	1.9	2.16	2.74	2,551
2004	2.89	2.91	11	7.27	3.15	3.38	2.14	1.73	1.81				
Mean	7.9	7.1	13.9	15.4	18.3	8.4	3.8	3.0	3.0	3.2	3.5	4.0	5,528

YEAR	Monthly mean streamflow, in ft^3/s for 10309035 (Indian Creek)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1994					9.85	2.09	0.4	0.12	0.09	0.22	0.54	0.65	
1995	6.06	5.02	73	19.7	8.64	9.96	13.8	10.2	4.97	2.45	1.56	4.85	9,749
1996	10.3	38.1	27.1	10.3	12.4	15.7	8.58	4.59	3.2	2.85	1.85	6.25	8,395
1997	78.2	17.2	6.85	8.61	9.35	8.06	1.77	0.31	0.26	0.77	0.65	0.74	8,027
1998	0.57	12.9	32.5	11.4	18.3	26.1	21	2.47	1				
Mean	23.78	18.31	34.86	12.50	11.71	12.38	9.11	3.54	1.90	1.57	1.15	3.12	8,724

YEAR	**Monthly mean streamflow, in ft^3/s for 10309000 (E. Fork between state line and Dresslerville, NV)**												**Total Acre-Feet**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1890	390	400	780	946	2,541	2,417	1,794	597	414	386	384	379	692,057
1891	388	402	456	530	1,429	1,328	618	408	388	385	385	438	432,340
1892	390	392	422	478	1,226	1,158	506	413	414	416	414	1,100	443,429
1893	545	424	749	1,139	1,628	2,021	1,461	507	416	408	424	404	612,176
1901	34.1	664	464	582	1,823	1,492	741	259	139	137	196	280	410,075
1902	81.2	77.8	101	601	1,204	955	178	131	54.1	51.4	86.1	53.6	215,945
1903	32.4	31.1	135	890	1,792	1,714	356	143	72.8	93	229	57.5	335,054
1908	250	148	183	470	555	539	221	131	128	116	106	111	178,537
1909	508	200	199	754	1,377	2,016	665	169	125	127	282	313	406,633
1910	200	206	534	1,069	1,243	703	252	82.4	94.3	90	92.1	128	283,504
1925	73.5	202	277	738	1,434	949	393	126	86.6	80.9	75.2	76.1	272,524
1926	79.7	86.4	192	647	708	260	82.9	43	37	47.1	88.7	65	141,124
1927	75	305	321	684	1,377	1,571	549	146	84.3	87.7	128	93.9	326,676
1940	165	197	389	749	1,521	890	209	103	76.4	64.5	70	115	274,991
1941	97.3	139	217	330	1,435	1,069	380	124	80.4	86.8	128	325	267,241
1942	314	235	338	787	1,178	1,623	606	160	101	85	156	169	346,993
1943	333	230	410	1,011	1,416	1,015	422	142	93.2	72	73.3	81.9	320,135
1944	79.7	85.3	162	326	1,018	643	237	92.9	55.5	55.2	127	112	181,280
1945	114	362	216	678	1,468	1,229	492	138	103	120	170	221	320,087
1946	196	143	237	791	1,215	719	225	103	71.4	90.9	182	133	248,142
1947	88.4	155	235	470	992	408	133	60	44.2	77.7	77	64.3	169,546
1948	101	79.4	86	344	882	988	289	88.8	58.9	53.6	61.9	54.1	186,442
1949	53.1	75.1	112	730	1,137	703	152	74.2	47.6	57.5	68.2	58.1	197,413
1950	141	189	207	662	1,174	1,146	318	108	80.8	87.5	1,110	1,127	383,398
1951	284	284	253	565	914	750	227	105	81.9	70.5	85.9	124	225,600
1952	129	204	250	1,108	2,162	1,933	1,035	313	162	106	94.4	112	460,075
1953	201	154	185	588	727	1,189	617	163	100	81.5	87.8	81.7	251,901
1954	82.6	118	341	723	1,046	435	170	90.9	52.2	49.5	69.6	77.2	196,904
1955	74.9	93.5	125	241	817	778	185	92.4	51.7	48.9	61.8	914	211,374
1956	515	259	379	782	1,503	1,671	696	209	151	126	115	108	393,602
1957	108	237	239	413	908	1,091	271	104	65.4	75	83	86.5	221,645
1958	79.8	192	199	688	1,908	1,418	544	211	133	79.4	81.4	70.7	338,855
1959	129	143	220	494	545	410	126	65.9	70.2	55.5	49.9	45.7	141,874
1960	51	117	204	467	554	388	104	51.7	31.2	40.9	58.8	66.7	128,664
1961	57.4	90.7	111	370	566	407	111	57.1	45.7	46.5	46.1	51.2	118,236
1962	51.3	153	152	885	923	1,050	322	120	74.7	102	72.1	76.7	239,795
1963	255	800	224	380	1,333	1,300	488	167	145	99	207	147	332,163
1964	108	106	131	383	748	567	172	94.8	57.3	48.8	73.2	703	193,504
1965	378	284	260	702	1,224	1,318	648	325	192	133	147	152	347,989
1966	146	121	288	688	914	313	130	83.4	51.3	49.5	89.6	206	186,387
1967	170	198	487	308	1,553	2,031	1,176	296	172	119	106	95.1	406,286
1968	134	234	260	458	815	545	144	108	63.9	65.4	127	94.9	183,730
1969	400	198	354	1,140	2,516	1,967	811	261	151	137	109	185	498,132
1970	594	299	303	410	1,212	1,075	351	141	98.1	70.9	127	136	291,019
1971	217	221	261	486	1,001	1,360	537	163	108	92.5	118	131	283,294
1972	104	140	425	364	910	738	174	87.3	69.3	89.4	87.2	159	202,485
1973	166	143	180	596	1,615	951	224	138	93.1	83.5	362	223	288,761
1974	405	211	353	556	1,510	1,291	407	172	103	78.7	89.3	90.4	318,523

YEAR	Monthly mean streamflow, in ft^3/s for 10309000 (E. Fork between state line and Dresslerville, NV) Cont.											Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1975	92.2	115	219	276	1,431	1,728	556	164	124	142	146	108	308,470
1976	91.3	94.3	135	234	515	182	121	72.9	61.4	62.8	52.5	48.8	101,135
1977	49.2	59	67.8	185	205	259	62.9	29.5	19.4	31.9	44.5	85.2	66,180
1978	122	146	359	471	1,224	1,392	533	169	136	76.3	85.4	91.1	290,437
1979	199	166	290	516	1,369	820	216	126	80.8	78.7	88	85.5	244,134
1980	557	380	304	810	1,463	1,364	831	211	124	93.3	76.1	81.7	380,106
1981	78.4	139	148	495	687	370	98.3	70.5	44.8	61.1	282	437	175,808
1982	223	833	392	1,127	1,845	1,637	794	260	201	328	330	295	496,710
1983	270	340	555	519	2,273	3,056	1,479	529	280	183	505	509	634,835
1984	342	237	374	601	1,538	1,019	390	160	112	120	159	136	313,841
1985	117	130	176	747	833	437	142	98	96	96.7	97	149	188,259
1986	201	947	1,038	1,087	1,595	1,369	438	166	124	115	90.9	85.5	435,252
1987	80.3	106	120	452	545	190	87.3	52.8	33.6	46.6	63.4	93.8	112,936
1988	88.7	90.6	150	272	352	207	91.5	62	23.5	31.2	50	52.2	88,796
1989	48.1	101	439	805	819	718	179	97.3	79.2	78.7	76.9	77.5	212,428
1990	78.8	86.4	215	477	386	256	96.6	62.7	47.2	40.7	37.9	43.2	110,233
1991	52.4	45.8	117	270	635	574	144	76.6	57.1	60.7	96.2	84.6	133,848
1992	68.2	103	146	444	379	138	78	51.1	36	39.6	48.9	48.4	95,228
1993	110	118	551	725	1,693	1,259	514	157	102	78.7	71	74.4	330,322
1994	72.3	73.1	148	393	584	309	93.1	48.8	37.9	55.6	92.6	90.4	120,755
1995	239	256	749	760	1,704	2,411	1,731	495	193	119	96.5	158	539,568
1996	153	531	500	916	1,890	1,255	404	151	101	84.3	166	372	393,112
1997	1,789	413	543	902	1,442	924	294	163	102	78.1	86.9	93.3	413,531
1998	128	146	493	510	1,027	1,901	1,016	215	161	109	112	140	360,156
1999	158	281	279	535	1,613	1,421	437	166	106	77.1	86	77.2	316,040
2000	121	186	233	613	1,078	619	171	106	64.3	64.2	67.1	68.8	204,721
2001	63.1	72.9	198	419	1,000	223	92.8	54.6	40.5	45.2	63.5	82.4	142,892
2002	124	114	184	656	880	614	146	78.3	59.4	58.5	107	90.7	187,819
2003	163	145	229	355	1,081	1,103	211	117	75.4	62	61.7	88.5	222,964
2004	101	146	477	615	829	448	125	79	46.5				
Mean	201	219	298	607	1,192	1,043	421	158	108	101	143	181	282,170

Year	Monthly mean streamflow, in ft^3/s for 10309050 (Pine Nut Creek)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1981	0.74	0.85	0.86	0.97	0.64	0.27	0.07	0.08	0.13	0.33	0.67	0.57	371
1982	0.43	1.61	0.95	2.62	1.01	0.71	0.37	0.11	0.23	0.5	0.67	1.02	611
1983	1.21	1.31	4.1	5.04	9.44	7.26	7.78	11.6	1.18	2.03	5.7	3.33	3,642
1984	2.05	1.63	2.12	2.06	2.65	1.07	0.69	0.65	0.73	1.22	2.28	1.71	1,138
1985	1.33	1.26	2.1	2.77	1.38	0.8	0.42	0.3	0.42	0.56	0.82	0.95	789
1986	0.96	6.78	10.2	3.79	2.92	1.63	0.92	0.55	0.6	0.97	1.38	2.24	1,970
1987	1.88	1.79	1.67	1.13	1.1	0.78	0.35	0.24	0.29	0.57	1.16	0.89	711
1988	1.29	1.94	0.67	1.34	0.73	0.36	0.2	0.16	0.23	0.24	1.07	0.72	533
1989	0.68	1.09	1.61	0.96	0.93	0.73	0.2	0.13	0.39	0.98	0.73	0.6	543
1990	0.5	0.93	1.11	0.9	0.55	0.26	0.13	0.21	0.15	0.15	0.25	0.36	330
1991	0.33	0.42	0.8	0.96	0.56	0.34	0.11	0.08	0.11	0.13	0.33	0.44	277
1992	0.48	0.63	0.51	0.55	0.32	0.14	0.15	0.09	0.09	0.11	0.16	0.29	211
1993	0.36	0.49	2.08	1.71	1.74	0.92	0.13	0.08	0.07	0.17	0.24	0.22	496
1994	0.39	0.46	0.72	0.47	0.41	0.14	0.05	0.02	0.21	0.37	0.41	0.61	257
1995	1.04	1.09	1.74	1.66	10.6	8.41	1.99	0.37	0.34	0.48	0.62	0.87	1,768
1996	0.79	2.69	4.72	3.2	2.43	1.03	0.42	0.25	0.38	0.4	0.87	1.07	1,095
Mean	0.90	1.56	2.25	1.88	2.34	1.55	0.87	0.93	0.35	0.58	1.09	0.99	921

Year	Monthly mean streamflow, in ft^3/s for 10309070 (Buckeye Creek)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1981	0.04	0.04	0.06	0.1	0.06	0.01	0	0	0.01	0.17	0.12	0.1	43
1982	0.09	2.39	0.03	2.45	0.14	0.18	0.04	0	0.06	0.24	0.18	0.51	368
1983	1.46	3.23	6.88	7.08	6.07	4.23	0.11	0.51	0.59	0.47	0.96	1.64	1,999
1984	0.33	0.74	1.19	0.7	0.73	0.6	0.27	3.66	0.35	0.24	0.25	0.15	558
1985	0.06	0.09	1.24	1.77	0.16	0.06	0.03	0.06	0.6	0.32	0.08	0.11	275
1986	0.14	13.3	9.86	1.69	2.06	0.62	0.18	0.02	0.05	0.09	0.1	0.16	1,654
1987	0.24	0.38	0.66	0.12	0.5	0.07	0.06	0.02	0.04	0.45	0.13	0.13	169
1988	0.46	0.4	0.06	0.07	0.08	0.05	1.54	0.02	0.03	0.07	0.07	0.04	175
1989	0.05	0.96	0.45	0.08	0.24	0.4	0.01	0.05	0.45	0.31	0.35	0.35	219
1990	0.14	0.09	0.09	0.04	0.01	0	0	0.22	0.02	0.01	0.02	0.01	39
1991	0.01	0.02	0.04	0.04	0.09	0.1	0.68	0.25	0.14	0.21	0.08	0.02	102
1992	0.01	0.03	0.02	0.07	0.04	0	0.1	0	0	0	0	0	17
1993	0	3.22	15	0.75	0.01	0	0	0	0	0	0	0	1,146
1994	0	0.07	0.01	0	0	0	0.05	0	0	0	0	0.25	23
1995	1.75	0.99	10.1	2.31	10.9	2.67	0.44	0.05	0	0.04	0.07	0.31	1,806
1996	0.26	5.5	13.1	0.91	0.69	0.56	0.37	0.11	0.14	0.22	0.26	0.62	1,362
Mean	0.31	1.97	3.67	1.14	1.36	0.60	0.24	0.31	0.16	0.18	0.17	0.27	622

YEAR	**Monthly mean streamflow, in ft^3/s for 10309100 (E. Fork at Minden, NV)**												**Total Acre-Feet**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1974				330	993	896	81	4.01	2.9	1.72	12.1	32.2	
1975	37.3	74.9	159	201	998	1,321	155	2.94	2.35	39.8	75.3	66.5	189,030
1976	54	28.3	60.3	12.2	102	4.78	2.8	1.56	1.3	1.17	0.82	1.17	16,420
1977	1.48	2.59	1.45	1.41	9.49	18.6	0.75	0.35	0.14	0.23	2.83	29	4,140
1978	67.9	78.4	285	317	833	988	186	2.67	5.35	2.66	22.6	22.6	169,745
1979	165	169	221	309	955	393	6.15	1.64	1.43	10.2	54.2	68.2	142,224
1980	655	352	257	596	1,079	944	484	13.6	3.4	3.7	3.14	12.9	265,617
1981	15.9	72	57.6	199	258	69.5	1.31	1.08	1.22	3	193	406	77,212
1982	221	725	313	1,037	1,506	1,154	472	36.5	61.8	215	244	236	373,272
1983	255	334	527	420	1,387	1,854	1,124	257	45.7	80.9	405	528	436,407
1984	335	217	297	397	1,220	636	80.9	3.15	3.07				
1994			57.9	136	275	62.8	2.56	1.38	1.53	5.1	25.8	46.8	
1995	170	116	1,011	921	2,033	2,554	1,502	149	16.9	25.9	45.8	154	527,157
1996	157	667	521	798	1,786	1,128	294	21.4	8	4.69	118	304	349,030
1997	1,221	378	413	668	1,090	903	80.3	5.14	3.24	22.7	47.2	41.7	294,185
1998	76.9	111	412	392	678	1,577	564	48.6	11.4				
Mean	245	238	306	421	950	906	315	34	11	30	89	139	237,037

YEAR	**Monthly mean streamflow, in ft^3/s for 10310448 (Ambrosetti Pond Outlet)**												**Total Acre-Feet**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1992									2	2	2.13	2.24	
1993	2.02	1.76	1.61	0.58	0.53		1.82	1.62	1.65	14.5	10.8	6.78	
1994	8.12	12.6	11.2	11.4	16.9	7	0.53	0.59	0	3.65	7.4	9.13	5,317
1995	23.9	19	29.7	7.8	18.2	16.1	15.6	9.34	7.36	13	15.6	18.2	11,710
1996	31.1	33.5	29.7	8.93	42.3	25.7	9.81	2.19	0.74	12	36.2	34.2	16,037
1997	81.6	16.1	12.2	28.8	29.5	50.6	10.8	2.32	6.43				
1998										29.3	30.1	10.6	
1999	18.3						8.83	9.69	2.21	10.5	15.4	13.8	
2000		7.03	8.65	24.9		27	8.27	1.67	0.33	1.63	16.8	15.2	
2001	11.5	13.3	9.3	23.9	12.8	12.4	1.25	0.05	0	0	4.74	7.95	5,815
2002	5.92	5.29	4.18	13.7	26.9	20.2	6.73	0.15	0	0	4.44	13.4	6,097
2003	16.2	12.8	8.87	20.6	20.1	22.2	8.65	9.57	1.54	0.6	6.78	9.13	8,249
2004	8.01	8.95	13	17	28.8	25.8	2.1	0.04	0				
Mean	16.1	16.1	15.5	14.4	22.9	17.3	7.1	3.65	1.61	4.88	12.5	15.3	8,871

YEAR	**Monthly mean streamflow, in ft^3/s for C82 (Allerman Canal)**								**Total Acre-Feet**
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		67.7	111.0	91.0	96.1	51.7	24.8		26,829
1985		61.1	111.0	98.5	47.2	33.2	29.1		23,004
1986		45.4	103.9	78.1	92.9	54.3	32.3		24,705
1987		57.8	98.2	74.6	31.6	21.7	12.0		17,912
1988		86.9	97.5	68.6	31.0	21.4	6.5	0.0	18,852
1989		94.6	106.2	81.5	67.0	28.1	22.0	1.9	24,287
1990		110.7	114.0	99.8	50.7	20.3	14.2	3.6	24,978
1991	35.5	78.3	115.3	130.7	46.5	28.3	25.0	0.0	27,800
1992	26.7	96.1	106.7	46.7	21.8	14.0	14.3	4.9	20,051
1993	1.4	68.9	90.1	74.6	92.5	46.7	29.4	6.8	24,894
1994	4.2	84.0	86.4	79.0	32.9	32.0	23.7	6.1	21,047
1995		46.7	62.8	127.7	123.8	138.4	114.3	26.0	38,761
1996		70.8	105.5	109.4	118.4	70.4	63.9	30.3	34,481
1997	17.6	68.7	91.7	93.3	105.4	55.8	49.6	13.2	30,029
1998		40.3	76.4	94.4	104.1	81.6	62.7	21.0	29,160
1999	0.7	24.2	78.2	83.9	88.1	61.5	39.7	19.2	24,020
2000	7.6	62.7	92.9	90.9	57.6	36.6	30.1	9.7	23,493
2001	12.1	72.3	100.8	64.9	27.2	14.5	14.8	6.9	18,977
2002	7.7	81.0	98.7	90.8	54.2	34.2	23.4	3.9	23,824
2003	13.0	51.1	83.8	89.4	75.6	44.6	40.0	14.7	24,985
2004	16.0	72.1	80.3	94.4	47.2	30.6	21.8	7.2	22,360
Mean	12.9	68.6	95.8	88.7	67.2	43.8	33.0	10.3	24,974

YEAR	Monthly mean streamflow, in ft^3/s for C83 (Virginia Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		51.1	57.7	48.2	45.5	7.6	0.2		12,737
1985		33.3	63.5	53.7	5.1	1.6	2.4		9,636
1986		35.9	82.4	66.3	57.8	10.5	8.4		15,843
1987		50.4	80.9	18.3	5.1	1.2	0.0		9,452
1988		35.5	50.6	30.0	14.9	9.5	0.0		8,510
1989		52.6	76.9	75.5	13.5	0.2	0.0		13,189
1990		39.8	48.0	24.5	1.6	2.0	2.6	0.7	7,201
1991		18.0	68.1	57.3	14.8	4.4	9.3		10,408
1992	0.6	51.8	43.7	7.3	6.8	6.9	1.6		7,185
1993	0.0	31.1	65.7	59.3	47.0	3.4	0.8	0.7	12,613
1994	0.6	44.2	47.8	32.3	0.6	1.0	0.0		7,621
1995		5.0	34.2	55.8	54.8	45.0	1.9	0.0	11,969
1996		29.4	51.2	55.3	46.5	5.2	5.0	3.3	11,872
1997	5.1	67.1	82.0	75.1	48.1	5.4	4.5	0.8	17,428
1998		13.3	40.3	49.4	75.5	25.9	3.7	0.8	12,709
1999	0.2	18.7	69.4	63.4	27.5	14.7	7.6	1.7	12,318
2000	5.9	62.7	76.9	82.0	17.6	7.6	1.6	0.6	15,386
2001	7.5	39.3	77.1	35.0	2.9	3.9	0.7	0.0	10,076
2002	3.3	68.1	87.5	90.2	11.7	4.2	0.2	0.0	15,990
2003	5.5	49.2	82.5	83.5	20.5	7.0	2.1	0.0	15,126
2004	3.1	38.5	67.0	70.1	5.3	1.7	0.3	0.0	11,220
Mean	3.2	39.8	64.5	53.9	24.9	8.0	2.5	0.7	11,833

YEAR	Monthly mean streamflow, in ft^3/s for C84 (Rocky Slough)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		52.9	128.3	104.6	60.9	28.0	18.4		23,821
1985		46.3	120.2	72.1	25.5	11.7	11.5		17,408
1986		55.3	139.3	96.3	80.7	36.6	25.8		26,334
1987		75.8	94.1	43.7	18.9	8.9	3.0		14,787
1988		69.2	78.3	47.3	18.3	11.2	8.2	0.7	14,097
1989		80.8	97.9	93.6	43.4	26.0	14.6	1.6	21,635
1990		62.7	70.3	48.6	9.8	3.2	0.2	0.0	11,749
1991	1.8	27.9	70.4	78.7	20.0	2.2	0.6	0.0	12,178
1992	1.1	71.9	76.6	26.7	13.2	5.2	3.7	1.6	12,098
1993	0.4	30.6	77.4	83.7	70.6	33.2	16.3	1.3	19,009
1994	1.7	69.1	85.4	73.3	11.2	0.0	0.0	0.0	14,516
1995	0.0	28.7	61.5	72.1	84.1	71.7	43.9	3.4	22,180
1996	0.0	43.4	72.5	70.8	76.9	37.6	25.5	15.5	20,760
1997	9.9	63.5	75.5	70.8	65.2	31.7	21.7	6.3	20,874
1998		17.5	69.1	73.6	84.4	50.6	41.3	2.3	20,572
1999	0.5	26.9	74.0	80.3	76.3	34.6	12.7	0.6	18,565
2000	4.5	62.7	69.4	68.6	29.6	1.6	0.1	0.0	14,282
2001	11.7	61.0	90.4	40.8	15.5	0.5	0.1	0.0	13,332
2002	3.1	60.5	87.0	74.8	20.7	0.3	0.3	0.2	14,908
2003	0.0	43.7	63.8	44.4	33.8	11.3	1.9	0.5	12,084
2004	5.1	68.9	73.2	53.1	4.3	5.1	0.2	0.2	12,681
Mean	3.1	53.3	84.5	67.5	41.1	19.6	11.9	2.0	17,042

YEAR	**Monthly mean streamflow, in ft^3/s for C85 (Edna Slough)**								**Total Acre-Feet**
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		22.3	40.1	34.8	26.2	5.7	1.4		7,916
1985		19.6	41.9	36.1	18.6	11.7	6.7		8,149
1986		15.9	37.3	37.0	30.1	6.7	3.8		7,933
1987		24.4	31.7	13.1	5.4	2.0	0.0		4,632
1988		17.2	27.3	12.3	9.1	5.0	0.0		4,294
1989		33.9	39.0	36.5	11.4	7.7	3.3		7,959
1990	0.8	21.0	20.3	12.6	2.7	1.2	0.8		3,585
1991		8.7	15.2	19.8	4.0	1.3	0.6		3,001
1992	0.2	18.2	19.5	3.8	1.4	0.9	0.2		2,669
1993		7.4	18.9	19.3	13.5	6.2	3.8	0.4	4,208
1994	1.1	16.5	17.7	16.8	3.4	0.1	0.0		3,358
1995		11.4	21.6	22.2	22.6	21.3	17.0	2.2	7,170
1996		21.3	26.7	32.3	40.0	7.3	3.8	1.4	8,049
1997	1.6	23.5	28.5	28.9	24.4	5.1	1.0	0.1	6,847
1998		8.8	20.8	22.5	30.1	18.7	5.4	0.1	6,476
1999	0.3	14.5	20.3	21.2	21.3	3.1	0.8	0.1	4,950
2000	7.4	21.7	21.0	25.9	9.6	2.6	1.2	0.2	5,415
2001	4.0	16.8	23.1	10.4	1.1	0.0	0.0	0.0	3,347
2002	0.0	22.7	26.0	27.1	4.0	0.0	0.0	0.0	4,804
2003	0.3	15.3	21.6	24.5	10.6	4.3	0.6	0.0	4,670
2004	0.0	19.8	22.3	21.5	1.8	2.6	0.0	0.0	4,105
Mean	1.6	18.1	25.8	22.8	13.9	5.4	2.4	0.4	5,407

YEAR	**Monthly mean streamflow, in ft^3/s for C87 (Cottonwood Slough)**								**Total Acre-Feet**
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		26.0	43.0	53.6	29.6	13.4	7.8		10,489
1985		21.7	36.2	35.1	18.2	0.0	0.0		6,723
1986		29.3	50.1	43.6	35.9	10.7	10.1		10,887
1987		29.3	36.8	15.3	8.2	6.3	4.8		6,097
1988		18.4	24.1	11.6	9.1	7.8	2.1	0.0	4,427
1989		25.9	24.6	35.0	15.9	10.1	8.9	0.5	7,291
1990		21.8	20.8	13.4	12.0	8.1	3.2	1.5	4,893
1991	5.2	17.8	27.2	27.4	20.0	7.0	3.5	0.0	6,544
1992	0.2	22.2	35.9	16.0	12.1	0.6	0.3	0.0	5,291
1993	0.1	5.9	18.9	20.0	14.7	7.1	13.6	2.5	5,011
1994	0.4	16.6	8.8	23.2	8.9	2.2	0.0	0.0	3,617
1995		4.8	16.8	18.7	19.8	15.9	5.4	4.3	5,206
1996		9.2	31.2	29.1	22.6	16.1	13.5	3.3	7,585
1997	0.1	12.5	19.0	23.9	14.2	11.6	2.2	1.1	5,128
1998		5.9	11.8	9.4	19.5	9.7	13.3	5.4	4,555
1999	0.0	9.8	30.3	20.7	21.3	20.3	16.2	2.3	7,336
2000	0.3	9.5	22.6	16.1	17.7	17.4	10.7	1.9	5,840
2001	1.9	12.3	26.3	24.9	26.5	22.1	14.2	8.6	8,303
2002	0.8	12.5	27.6	23.2	16.8	6.7	9.4	2.0	6,003
2003		0.5	28.0	13.0	11.5	3.5	1.2	0.0	3,525
2004	2.2	11.5	31.2	23.0	20.5	3.9	3.5	1.2	5,886
Mean	1.1	15.4	27.2	23.6	17.9	9.5	6.8	2.0	6,221

YEAR	Monthly mean streamflow, in ft^3/s for C88 (Henningson Slough)								Total Acre-Feet
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		8.6	26.3	19.4	17.9	12.2	3.7		5,349
1985		11.7	23.0	20.5	7.3	4.4	5.1		4,353
1986		12.1	21.3	17.0	17.7	11.6	10.6		5,471
1987		21.2	20.8	10.0	5.0	0.0	0.0		3,437
1988		14.5	16.5	14.0	3.7	2.2	0.4		3,099
1989		13.4	14.8	14.2	10.2	5.0	3.0		3,671
1990		23.7	21.8	18.2	13.5	9.7	5.9	0.2	5,614
1991		8.5	18.1	18.0	7.7	2.4	3.0		3,486
1992	0.1	13.7	17.2	8.3	3.8	1.7	1.2		2,786
1993		11.3	17.1	11.9	13.3	10.8	7.1	0.6	4,375
1994	0.6	14.7	14.4	8.8	3.3	0.9	0.0		2,583
1995		8.1	12.2	15.2	19.4	15.9	14.5		5,173
1996		9.3	25.2	23.2	21.3	16.6	11.8	4.6	6,801
1997	2.8	21.3	29.4	23.0	18.9	10.4	8.8	2.8	7,117
1998		5.7	18.5	12.8	23.1	14.3	13.1	0.7	5,357
1999	0.2	11.1	18.5	19.0	18.2	12.1	10.4	3.2	5,619
2000	0.6	22.0	23.4	20.2	15.4	5.9	2.3	0.3	5,447
2001	2.7	20.7	27.3	18.2	5.2	1.2	0.5	0.1	4,588
2002	2.9	27.6	21.1	23.9	10.2	4.0	2.3	1.6	5,640
2003	4.4	16.2	24.7	22.9	16.4	8.6	3.5	0.6	5,895
2004	6.2	24.2	28.1	22.4	11.6	5.4	3.2	1.4	6,208
Mean	2.3	15.2	20.9	17.2	12.5	7.4	5.3	1.5	4,860

YEAR	Monthly mean streamflow, in ft^3/s for C89 (Heyburn Ditch)								Total Acre-Feet
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		28.1	48.9	44.9	39.7	7.1	2.2		10,360
1985		25.8	45.5	39.4	3.2	1.2	0.0		6,946
1986									
1987		25.5	62.5	23.6	5.5	2.5	0.0		7,258
1988		18.8	29.9	16.9	4.2	5.1	0.0		4,536
1989		38.5	54.8	40.8	10.4	6.3	1.3		9,191
1990		37.8	47.5	34.3	4.7	3.4	2.6		7,863
1991		13.4	46.7	44.5	6.8	2.5	0.0		6,888
1992	0.7	30.6	29.1	7.8	2.4	1.5	1.9		4,465
1993		16.8	37.6	38.1	35.5	5.4	0.9		8,144
1994	1.2	33.1	40.0	24.4	0.7	0.9	0.1		6,059
1995		13.7	30.4	52.1	37.6	29.8	9.6	3.3	10,701
1996		22.0	35.3	34.3	29.9	0.1	0.4		7,388
1997	2.1	26.2	46.2	56.8	23.3	8.8	9.8		10,466
1998		2.7	17.2	22.9	40.8	14.0	1.9	0.2	6,077
1999	0.2	9.5	26.3	30.1	20.5	6.2	0.5	0.4	5,687
2000	2.2	23.7	34.3	30.3	5.4	2.2	1.1		5,985
2001	2.5	18.0	24.1	10.4	0.8	0.5	0.0		3,407
2002	1.7	26.0	29.6	31.1	3.8	1.0	0.2	0.1	5,637
2003	0.5	12.0	26.3	29.7	7.6	1.4	1.0	0.3	4,759
2004	5.6	18.0	21.8	22.9	2.6	0.7	0.1	0.0	4,326
Mean	1.8	22.0	36.7	31.8	14.3	5.0	1.7	0.7	6,807

Appendix C: Main Carson River Historical Data

YEAR	Monthly mean streamflow, in ft^3/s for 10311000 (Carson River s. of Carson City)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1939						86	10.7	6.77	14.3	65	65.2	92.9	
1940	372	349	523	883	1,559	690	74.8	13.9	19.9	49.9	86.3	197	290,832
1941	219	243	311	323	1,653	993	209	35.7	31.5	100	181	472	288,896
1942	780	484	460	936	1,405	1,719	465	45.5	47.2	77.2	314	327	425,240
1943	865	449	769	1,316	1,528	1,046	265	42.5	37.7	78.3	131	168	404,005
1944	197	207	293	283	950	486	92.9	19.6	14.8	39.8	201	206	180,672
1945	200	602	352	688	1,661	1,176	329	36.5	30.2	136	299	425	356,983
1946	375	266	357	928	1,288	536	95.7	20.9	31.4	84.5	330	256	275,707
1947	187	256	303	372	886	257	25.2	12.2	12.9	51.2	106	99.4	154,890
1948	159	113	78.6	217	886	913	157	15.9	14.9	35.2	71.4	86.7	165,867
1949	80.6	165	203	662	1,273	461	33.9	15.1	12.1	32.5	83.7	86.4	187,725
1950	262	279	253	733	1,238	1,186	167	22.9	22.8	82.1	1,693	1,991	478,722
1951	582	469	395	493	806	553	72.7	24.1	29.2	75.9	152	293	237,341
1952	297	475	497	1,397	2,623	2,327	1,008	275	108	124	165	247	576,030
1953	396	275	289	673	788	1,240	453	47	54.8	85.1	150	156	277,434
1954	174	226	485	742	944	235	36.4	19.2	16.8	29.7	91	138	189,399
1955	129	161	149	129	686	634	51.1	14.6	16.5	31.5	66.5	1,688	228,327
1956	905	494	503	953	1,782	1,910	572	92.9	75.1	167	210	183	473,316
1957	178	435	378	374	967	999	113	21.8	21.8	58.9	121	150	229,137
1958	154	328	341	808	2,219	1,495	397	84.3	62.4	83.7	133	143	377,297
1959	234	325	293	311	415	159	21.4	7.33	13.2	32.1	55.6	73.9	116,318
1960	99.6	208	184	312	336	155	19.4	13.7	4.57	20.9	63.2	94.5	90,603
1961	83.2	115	86.1	153	332	266	18.1	7.46	12.4	26.8	58.8	82	74,642
1962	76.5	382	245	939	1,037	944	161	21.6	18.8	120	91.3	119	249,271
1963	190	1,704	327	509	1,383	1,455	261	34.6	36.6	101	321	217	387,341
1964	166	152	196	285	697	427	34.5	10.8	13.7	23.3	93.4	986	187,144
1965	754	399	354	829	1,366	1,414	487	287	174	175	294	239	408,649
1966	251	216	345	613	784	150	17.9	9.03	9.5	32.8	96	297	170,465
1967	335	338	776	461	1,775	2,402	1,162	156	145	166	172	167	486,971
1968	206	412	398	371	753	335	26.9	11.5	18.2	48.7	149	148	172,737
1969	714	410	563	1,312	3,129	2,430	641	97	81.2	198	187	362	612,128
1970	1,042	520	445	485	1,151	1,017	184	23.5	38.4	94.4	230	285	332,522
1971	375	362	427	558	1,206	1,442	373	72.5	49.8	130	190	242	327,120
1972	254	257	578	316	829	638	35.3	13.4	28.6	118	141	234	207,904
1973	380	355	334	618	1,674	863	71.7	30	23.6	84.4	508	407	322,779
1974	725	346	531	614	1,626	1,208	228	59.3	35.1	82.4	158	159	348,844
1975	153	270	427	423	1,392	1,857	362	63.8	45.6	163	250	212	338,752
1976	168	167	208	96	282	117	12.9	20.4	22.3	48.5	64.9	62.3	76,458
1977	77.5	108	73.7	46.4	93.9	115	11.6	2.81	1.96	7.69	46.6	141	43,591
1978	217	243	471	504	1,267	1,432	331	39.3	79.8	78.4	167	132	299,300
1979	458	317	372	527	1,421	607	75.8	17.7	16.2	87.2	165	187	256,886
1980	1,087	741	465	919	1,775	1,399	758	93.4	108	125	133	177	468,920
1981	168	267	214	419	538	213	11.9	4.68	5.65	47.7	406	650	177,420
1982	445	1,201	560	1,467	2,111	1,754	728	144	242	527	616	601	623,997
1983	607	677	985	707	2,368	4,099	1,569	657	281	379	1,014	921	860,942
1984	650	496	594	724	1,751	1,081	270	71.8	68.3	224	344	274	395,283
1985	240	272	288	895	704	258	28.4	14.5	51.4	140	164	217	196,876
1986	342	2,115	1,573	1,263	1,666	1,469	290	70	102	192	171	172	560,983
1987	187	204	201	252	361	83.4	19.7	13.5	14.8	34.5	80.1	93.1	92,877

YEAR	Monthly mean streamflow, in ft^3/s for 10311000 (Carson River s. of Carson City) cont.											Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1988	140	111	105	98.5	153	47.7	13.3	7.91	6.11	14.1	50.5	52.4	48,099
1989	137	185	491	859	705	552	30.1	10.3	16.4	79.7	113	123	198,848
1990	160	157	180	278	201	66.7	35.2	21.7	19.8	49.8	108	79.6	81,556
1991	76.4	62.7	189	193	458	371	43.8	21.5	20.2	66.7	130	126	106,326
1992	128	145	162	236	170	48.2	18.7	5.48	8.28	17.6	50.4	65.6	63,343
1993	203	303	633	742	1,879	1,258	313	41.2	27	99.8	112	129	346,898
1994	143	146	172	184	393	122	15.7	5.59	5.75	42.8	90.2	137	87,925
1995	372	324	1,303	920	2,300	2,984	1,764	289	82.9	140	161	300	662,523
1996	371	930	842	1,106	2,128	1,237	299	71.9	57.6	101	303	706	490,388
1997	3,171	738	819	1,084	1,603	1,031	145	58.7	73	127	161	180	556,072
1998	258	377	848	711	1,337	2,296	1,031	129	153	237	239	277	476,343
1999	354	601	421	679	1,951	1,555	288	74.4	62.7	118	161	158	386,496
2000	244	354	339	561	1,069	440	61.1	23.7	26.9	56.5	126	128	206,461
2001	125	148	241	294	696	68.2	17.5	6.97	4.31	18.6	81.1	134	111,043
2002	195	160	214	625	743	422	34.1	12.5	11.7	34.2	161	175	168,028
2003	246	244	252	353	1,014	1,014	75.9	28.1	22.6	29.5	84.4	147	211,480
2004	159	226	489	486	591	210	21	7.05	6.51				
Mean	364	386	418	604	1,181	946	258	57	46	96	203	281	295,115

YEAR	Monthly mean streamflow, in ft^3/s for 10311300 (Eagle Valley Creek)											Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1985	10.7	14	10.8	6.97	3.23	2.81	2.13	2.36	4.77	5.99	7.94	9.46	4,862
1986	10.7	91.9	24.5	11.5	9.2	9.67	5.52	3.84	4.41	11.8	7.98	9.21	11,698
1987	10.4	10.1	9.43	3.73	2.36	1.83	2.02	2.33	5.52	0.52	1.23	1.02	3,020
1988	3.88	1.8	0.35	1.94	0.21	0.13	0.02	0.01	0.02	0.12	2.43	0.26	667
1989	0.64	1.75	1.5	0.23	0.76	0.99	0.04	0.37	0.65	1.04	1.38	0.63	597
1990	1.03	1.44	1.26	1.16	0.21	0.13	0.32	0.14	0.36	0.1	0.24	0.42	406
1991	0.32	0.42	2.01	0.5	0.44	0.2	0.14	0.13	0.1	0.52	1.23	0.73	408
1992	0.57	0.91	1.09	0.34	0.17	0.25	0.1	0.15	0.17	0.24	0.25	2.81	426
1993	4.9	2.87	2.1	0.45	0.36	0.61	0.18	0.25	0.2	1.73	0.41	0.5	875
1994	0.25	0.83	0.41	0.15	1.39	0.08	0.1	0.03	0.07	0.25	0.89	0.25	282
1995	8.3	0.7	16.2	1.15	1.8	0.5	0.12	0.08	0.13	0.13	0.27	4.1	2,050
1996	6.89	25	17.6	2.7	2.64	0.58	0.14	0.21	0.08	0.41	6.08	25.4	5,227
1997	81.9	14.8	6.42	2.65	3.54	8.51	0.23	0.07	0.53	0.41	1.45	1.64	7,397
1998	5.37	8.18	14.3	2.09	2.84	6.34	0.67	0.15	2.8	0.65	3.2	2.09	2,916
1999	7.86	9.64	4.53	3.91	1.64	0.76	0.41	0.41	0.22	0.73	0.73	0.41	1,853
2000	7.98	7.1	2.49	1.67	1.99	0.75	0.15	0.09	0.14	0.27	2.11	1.13	1,539
2001	0.71	0.67	0.75	1.91	0.67	0.19	0.15	0.01	0.02	0.1	1.73	6.11	789
2002	1.63	1.14	1.16	0.74	0.36	0.05	0.29	0.07	0	0.04	2.95	7.78	982
2003	1.99	0.7	0.78	1.58	0.49	0.17	0.07	0.25	0.04	0.08	0.59	2	529
2004	1.19	1.82	0.51	0.34	0.36	0.29	0.04	0.09	0.07				
Mean	8.4	9.8	5.9	2.3	1.7	1.7	0.6	0.6	1.0	1.3	2.3	4.0	2,449

YEAR	**Monthly mean streamflow, in ft^3/s for 10310500 (Clear Creek)**												**Total Acre-Feet**
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1948			4.16	6.48	7.7	4.22	1.82	1.46	1.43	1.99	2.79	3.96	
1949	4.15	5.18	6.38	9.42	6.97	3.05	1.45	1.22	1.56	2	3.46	3.45	2,904
1950	6.93	6.55	7.99	11.5	9.44	5.78	3.39	2.42	2.3	3.36	11.2	15.3	5,198
1951	10.2	10.2	8.04	7.81	6.27	3.48	2.66	2.52	2.46	3.92	5.6	6.18	4,165
1952	5.59	9.6	11.6	30.9	26.8	15	8.09	5.75	5.73	6.54	7.48	8.79	8,549
1953	12	9.44	9.65	10.8	8.61	6.94	3.79	2.99	3.05	3.84	4.54	5.73	4,898
1954	6.21	7.15	8.3	7.97	4.16	2.99	2.27	2.03	2.23	2.63	3.45	5.14	3,277
1955	4.88	5.27	5.72	5.33	5.3	3.14	2.12	1.8	1.82	2.13	3.27	11.3	3,144
1956	11.1	9.59	11.2	12.4	14	8	3.99	3.1	2.83	4.21	4.7	5.78	5,477
1957	5.48	7.29	7.75	7.27	6.4	3.73	2.25	1.82	1.96	2.82	4.49	5.4	3,406
1958	6.07	8.97	7.3	12.4	15.8	6.82	4.36	3.08	3.04	3.35	4.85	5.17	4,886
1959	6.96	5.74	6.2	5.21	3.83	2.25	1.69	1.85	2.42	2.47	3.11	3.49	2,721
1960	4.27	6.11	5.41	4.21	2.66	1.73	1.25	1.13	1.15	1.54	3.27	3.35	2,162
1961	3.54	4.25	3.82	3.3	2.78	1.71	1.1	1.07	1.4	1.57	1.89	2.31	1,725
1962	2.13	5.59	5.69	7.24	4.44	2.66	1.67	1.32	1.3				
1989		7.03	9.28	8.86	4.92	3.45	1.93	1.98	2.04	2.64	3.33	3.61	
1990	3.65	4.91	4.73	3.94	2.75	1.51	1.28	1.74	1.55	1.56	1.97	2.46	1,924
1991	3.07	3.24	4.25	3.59	2.63	1.67	1.07	1.12	1.93	1.69	2.48	2.77	1,776
1992	3.04	3.42	3.36	2.8	1.39	1.46	0.94	0.71	1.05	1.41	2.05	4.04	1,543
1993	4.84	4.14	10.2	9.21	7.68	3.86	1.93	1.4	1.56	2.15	2.35	2.48	3,127
1994	2.89	3.85	3.4	3.48	2.8	1.12	0.75	0.67	1	1.31	2.22	2.77	1,576
1995	4.79	4.65	10.6	9.1	15.5	12.2	5.85	3.31	2.35	2.52	3.38	4.65	4,770
1996	5.26	11.8	14.1	14.1	15.7	8.28	4.65	3.75	3.59	4.45	7.47	12.3	6,347
1997	36.3	16.4	19.3	19.2	15	11.1	7.68	6.01	5.77	6.14	7.1	5.67	9,389
1998	8.92	8.35	14.9	15.6	15.9	15.5	8	5.49	5.41	6.37	7.88	8.89	7,315
1999	10.2	13.5	14.5	15.4	16.7	11.3	6.45	4.87	4.5	4.95	6.54	6.91	6,966
2000	8.3	10.2	9.89	9.62	7.92	4.53	3.06	2.48	3.23	3.9	5.33	5.63	4,450
2001	5.41	5.82	6.39	6.05	4.07	2.69	2.18	1.84	1.79	1.98	3.75	5.65	2,865
2002	5.66	5.07	5.99	6.6	4.63	2.44	2.05	1.73	1.73	2.11	3.71	3.8	2,740
2003	5.74	5.22	5.07	5.34	5.01	2.62	1.95	1.86	1.85	2.06	3.07	4.16	
2004	4.28	4.86	6.14	4.18	3.24	2.07	1.81	1.71	1.55				
Mean	7.0	7.1	8.1	9.0	8.1	5.1	3.0	2.4	2.4	3.0	4.4	5.6	4,127

YEAR	Monthly mean streamflow, in ft^3/s for 10311400 (Carson River at Deer Run Road)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1979					1,421	602	72.8	16	16.2	71.3	136	166	
1980	1,040	755	507	919	1,703	1,403	741	84.9	109	126	137	187	464,607
1981	177	276	220	404	523	201	12	3.97	2.63	40.3	392	680	176,653
1982	450	1,134	581	1407	2,114	1,826	756	116	227	534	633	641	625,782
1983	656	674	1,061	718	2,273	4,319	1,694	669	259	354	1,086	987	890,286
1984	649	472	559	704	1,801	1,126	262	73.7	70.3	241	368	284	399,131
1985	252	282	291	912	701	256	23.3	9.58	41.5				
1990								10.5	7.87	18.5	44.6	57.7	
1991	83.4	64.8	189	200	464	371	26.1	7.1	8.32	55.4	125	133	104,415
1992	114	121	146	220	144	23.5	4.37	2.63	2.92	19.7	60.1	80.1	56,368
1993	227	333	625	690	1,946	1,156	308	21.6	7.03	76.3	106	124	339,694
1994	131	137	151	168	364	98	3.75	2.49	0.7	31.5	95.2	132	79,302
1995	345	349	1,147	810	2,211	2,871	1,770	355	78.9	139	159	284	636,942
1996	430	981	887	1127	2,070	1,231	340	57.7	47.8	91.7	266	729	496,647
1997	3,106	840	877	1127	1,555	936	137	46.9	62	125	178	169	553,601
1998	293	377	835	728	1,395	2,207	1,037	118	144	240	238	299	477,613
1999	364	587	430	629	1,918	1,509	271	66.3	50.9	109	158	158	376,167
2000	258	383	347	529	992	418	43.2	18.1	16.3	47.9	117	129	198,398
2001	120	145	231	293	681	61.5	10.1	0.43	0	1.15	73.1	156	107,264
2002	197	171	230	576	672	390	19.2	2.74	3.74	24.4	152	163	156,694
2003	221	235	247	359	948	952	43.1	15.1	8.07	21.8	57.9	119	194,292
2004	148	202	487	529	582	210	8.26	0.04	0				
Mean	463	426	502	652	1261	1056	361	77	53	118	229	284	351,881

YEAR	Monthly mean streamflow, in ft^3/s for 10311700 (Carson River at Dayton, NV)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1994				155	366	98.2	1.22	0.26	0.14	17.9	79.7	124	
1995	364	323	1,315	912	2,206	2,854	1,786	314	57.9	120	152	314	649,219
1996	403	981	851	1,119	2,157	1,283	268	34.1	29	88.1	305	660	491,601
1997	3,125	788	838	1,100	1,607	999	126	34.9	43.8				
2002										11.5	156	170	
2003	229	230	235	308	941	978	28.8	9.77	3.76	10.6	70.4	141	191,795
2004	144	204	454	443	580	200	5.77	0.71	0.1				
Mean	853	505	739	673	1,310	1,069	369	66	22	50	153	282	444,205

YEAR	Monthly mean streamflow, in ft^3/s for 10312000 (Carson River w. of Fort Churchill, NV)												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1911					1,786	3,266	1,429	169	59.2	151	207	194	
1912	198	228	185	79.3	577	879	135	29.4	19.5	72.4	148	162	163,204
1913	189	232	223	231	761	487	87.4	43.2	33	40	91.6	146	154,617
1914	1,487	776	993	1,454	2,510	1,900	716	102	18.2	102	154	204	628,865
1915	249	417	367	591	1,023	1,363	432	34.3	14.1	50.4	188	318	303,562
1916	709	1,286	1,032	1,475	1,721	1,660	605	35.2	41.1	324	310	324	570,945
1917	313	536	455	849	1,480	2,304	796	44	29.8	36.9	126	200	431,102
1918	140	182	521	734	822	887	40.2	4.48	8.8	143	151	183	230,054
1919	183	253	250	762	1,813	465	22.8	7.87	2	31.9	93.5	215	247,917
1920	159	162	176	191	709	499	149	10.7	6.83	31.9	152	226	149,378
1921	329	343	475	475	1,265	1,326	280	21.1	9	35.7	128	197	294,412
1922	288	505	623	722	1,946	2,490	603	59	37	80.8	253	562	492,336
1923	351	367	457	631	1,401	904	400	37.1	0	25.9	271	360	314,282
1924	195	155	135	136	224	10.3	0	0	0	0	131	164	69,258
1925	183	458	336	674	1,329	822	303	30	10	80.8	118	134	269,387
1926	132	221	210	455	468	70.1	9.74	0	0	0	144	263	118,665
1927	252	497	413	745	1,427	1,537	348	23.7	11	61.9	196	143	339,799
1928	122	133	425	608	873	201	36.4	0	0	0	60	240	163,405
1929	113	121	87.2	106	476	266	28.7	7.61	8.4	11.3	27.4	127	83,301
1930	162	206	232	478	609	564	37.5	11.7	11	33.4	93.9	105	152,895
1931	135	141	105	142	262	41.5	13.1	4.13	4.1	6.19	21.1	99.5	58,675
1932	214	356	479	649	1,340	1,497	386	18	18	41	67	81	309,876
1933	121	137	206	154	264	819	97.6	24.5	13.5	26	137	178	130,854
1934	189	161	238	219	56.8	63.1	1.32	0	0	0	50.2	84.4	63,734
1935	96.2	151	153	668	1,096	1,030	155	3.52	0	8.84	111	116	216,168
1936	188	521	412	806	1,288	973	139	0	0	25.3	111	130	275,586
1937	167	802	387	496	1,375	782	101	6.58	0	14.2	82.8	769	298,900
1938	318	416	991	1,416	2,410	2,384	698	75.3	22	166	217	229	563,957
1939	226	221	298	564	321	74.3	2.16	0	0	59	86.8	115	118,211
1940	406	347	531	884	1,444	679	60.8	0	0	30.7	110	214	284,012
1941	232	252	306	257	1,487	939	206	0	0	84.9	191	436	265,739
1942	770	538	466	870	1,259	1,612	458	7.58	0	42	308	343	401,613
1943	776	530	791	1,235	1,403	993	271	0	0	63.1	160	213	387,794
1944	217	230	314	280	795	457	68	0	0	4.87	208	237	169,593
1945	236	610	386	616	1,466	1,071	325	0	0	61	299	405	329,081
1946	394	286	350	824	1,198	471	49.5	0	0	20.8	307	285	252,468
1947	229	277	308	305	772	234	0	0	0	0	85.9	135	141,358
1948	188	141	82.7	168	733	839	137	0	0	0	62.1	127	149,397
1949	79.8	171	214	543	1,166	409	0	0	0	0	50.8	115	166,001
1950	322	336	263	665	1,155	1,252	165	0	0	65.7	1,653	2,540	508,450
1951	611	467	341	303	592	414	22.3	0	0	19.9	123	200	185,751
1952	494	491	495	1,381	2,771	2,507	909	259	50.7	75.8	123	211	589,611
1953	378	293	296	560	719	996	341	0	0	40.1	103	156	233,670
1954	166	238	463	657	878	224	0	0	0	0	43	131	168,919
1955	141	176	149	109	518	633	2.52	0	0	0	30.9	1,326	187,138
1956	914	539	542	1,068	1,816	1,940	510	89	34.8	125	167	148	475,742
1957	137	333	278	286	1,014	1,119	110	0	0	17.7	120	163	214,981
1958	139	305	349	749	2,012	1,408	348	29.7	8.37	48.6	132	148	342,678

YEAR	Monthly mean streamflow, in ft^3/s for 10312000 (Carson River w. of Fort Churchill, NV) cont.												Total Acre-Feet
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1959	237	317	286	221	319	97.8	0.22	0.02	0.17	0.38	0.54	44.4	91,159
1960	85.5	205	162	194	217	80.5	0.25	0.07	0	0	19.5	81.2	62,454
1961	72.4	88.6	36.6	40.8	193	203	0.02	2.76	0	0.21	30.1	84.4	45,162
1962	83.1	402	258	857	954	851	115	0.1	0.07	84.2	61.7	104	225,920
1963	92.9	1,605	326	455	1,343	1,438	206	0.06	5.46	37.9	304	226	357,429
1964	183	164	177	186	590	381	5.91	0.03	0.08	0.02	48.8	844	156,433
1965	733	412	339	724	1,225	1,241	415	250	92.3	118	293	266	368,477
1966	276	228	326	528	678	121	0.1	0.05	0.06	0.02	33.4	319	151,602
1967	323	394	737	469	1,530	2,292	1,104	128	98.4	123	157	153	453,353
1968	210	398	402	314	638	295	2.6	0.65	0.82	2.04	116	150	151,703
1969	680	494	583	1,246	2,923	2,439	596	51.3	11.2	165	201	369	589,366
1970	1,030	538	449	452	1,014	963	161	2.68	2.17	39.9	207	305	311,088
1971	403	367	398	501	1,034	1,300	334	9.21	1.23	86.3	172	236	291,612
1972	244	256	554	250	684	613	4.88	0.49	0.42	77.3	126	245	184,367
1973	398	358	339	576	1,595	819	35.9	4.34	1.89	47.3	485	405	305,541
1974	688	355	490	528	1,451	1,185	211	15.6	3.43	59.4	161	163	320,694
1975	161	244	352	367	1,492	1,989	300	20.2	22.7	139	224	219	333,411
1976	180	174	190	46.9	144	13.2	0.79	0.31	0.14	10.3	58.5	64.4	52,995
1977	83.2	89.1	46.3	7.41	38.6	40.2	1.12	0.01	0	0	10.2	113	25,743
1978	230	252	456	429	1,106	1,343	294	13.1	25.7	21.2	140	125	267,359
1979	439	347	359	412	1,427	580	38.4	4.22	0.98	33.1	110	150	235,596
1980	1,060	742	495	846	1,611	1,268	708	58.5	60.2	95.5	125	193	437,566
1981	194	266	193	329	449	169	3.63	0.13	0.08	2.11	346	593	153,228
1982	418	1,076	584	1,432	2,042	1,699	716	96.8	189	481	616	612	598,326
1983	592	664	1,013	733	2,135	4,141	1,497	613	238	362	1,067	1,031	849,920
1984	729	494	577	693	1,646	1,075	234	25.5	44.7	216	332	274	382,656
1985	247	291	288	775	625	222	5.54	0.91	6.11	106	148	208	175,689
1986	333	2,378	1,414	1,132	1,505	1,442	303	40.6	50.4	189	177	189	543,097
1987	190	241	243	207	359	45.9	0.7	0.03	0.01	0.11	65.6	112	87,975
1988	159	132	92.4	48.2	79.6	26.8	0.25	0.02	0.03	0.11	29	76.3	38,589
1989	108	166	502	712	658	499	12.8	0.07	0.01	38.3	102	122	175,965
1990	144	151	179	244	169	42.6	0.17	0.05	0.04	0.06	13.6	56	59,965
1991	74.5	65.1	162	157	352	310	18.1	0.13	0.16	10.1	88.2	110	81,354
1992	119	125	123	171	114	4.8	0.22	0.04	0	0	1.9	79	44,280
1993	237	345	682	742	1,937	1,283	313	5.75	1.02	71.3	109	132	353,916
1994	127	134	148	123	317	91.5	3.77	0.39	0	0.9	64.7	114	67,778
1995	407	376	1,674	902	2,107	2,824	1,600	327	63.6	128	168	309	659,252
1996	400	1,079	1,066	1,230	2,220	1,255	320	34.5	19.4	66.9	319	697	523,347
1997	3,001	820	901	1,152	1,693	1,146	136	28.9	30.7	97.6	162	202	566,340
1998	294	442	848	706	1,340	2,190	969	119	90.6	251	266	300	471,488
1999	375	621	477	690	1,989	1,676	339	47.5	29.6	69.7	181	179	401,556
2000	258	397	361	546	1,149	432	31.7	6.21	5.03	10.6	104	127	206,236
2001	133	145	216	258	695	55.3	7.05	1.39	1.15	1.26	28.1	130	101,220
2002	179	144	185	505	586	369	6.44	1.51	1.18	1.84	111	140	134,305
2003	219	230	221	322	914	1,089	37.7	4.52	3.11	3.37	60.8	133	194,775
2004	144	192	455	402	524	196	5.01	2.18	1.16				
Mean	336	387	410	561	1,092	953	246	33	17	60	170	264	271,279

YEAR	Monthly mean streamflow, in ft^3/s for C61 (Mexican Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1989		25.4	26.8	19.0	12.0	8.1	4.9		5,818
1990		25.1	18.9	40.2	14.9	1.4	1.2		6,113
1991		25.3	15.4	31.3	13.0	2.2	0.0		5,252
1992		32.2	34.8	11.9	2.8	0.0	0.0		4,931
1993		26.3	26.8	20.7	18.3	24.6	13.9		7,906
1994		27.1	14.2	17.2	1.8	0.0	0.0		3,618
1995		26.2	23.2	20.5	11.4	34.3	21.5		8,293
1996		12.0	22.3	32.8	12.9	39.1	39.2		9,574
1997		25.8	34.0	3.3	14.7	42.1	37.0		9,517
1998		0.0	5.7	37.5	20.5	51.7	52.0		10,116
1999		23.1	27.2	38.4	21.3	48.3	42.6		12,144
2000		18.0	21.1	36.4	6.4	8.5	10.5		6,082
2001		8.2	16.0	11.4	3.3	0.0	0.0		2,349
2002		14.1	19.4	16.6	11.2	2.6	2.1		3,988
2003		18.3	18.7	6.4	24.0	8.0	15.4		5,505
2004		14.8	18.8	19.0	8.5	0.0	0.0		3,693
Mean		20.1	21.4	22.7	12.3	16.9	15.0		6,556

YEAR	Monthly mean streamflow, in ft^3/s for C62 (Rose Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		0.9	6.4	7.5	7.5	9.3	6.7		2,326
1985		3.9	5.0	4.4	6.0	2.6	4.7		1,606
1986		2.2	6.9	5.5	5.5	5.2	5.1		1,844
1987		2.9	4.0	4.5	2.9	2.3	2.6		1,160
1988		3.1	5.0	5.7	2.4	2.1	0.0		1,114
1989		3.3	7.0	6.3	5.0	5.7	4.5		1,921
1990		3.8	5.3	6.8	3.8	3.8	2.5		1,579
1991		3.2	5.7	5.8	4.7	4.1	0.0		1,429
1992		5.1	4.0	4.4	3.6	0.8	0.0		1,088
1993		2.9	6.9	5.5	4.8	6.1	5.0		1,887
1994		5.7	3.0	5.7	0.6	0.0	0.0		901
1995		0.5	2.2	3.3	4.0	5.4	5.7		1,275
1996		1.3	2.6	1.5	2.8	7.0	7.4		1,368
1997		5.0	8.1	2.3	2.6	3.0	6.5		1,661
1998		0.6	4.3	1.7	3.6	3.8	6.9		1,265
1999		1.3	5.1	3.2	5.6	3.8	3.7		1,374
2000		2.5	3.9	3.9	1.8	4.2	0.0		995
2001		3.3	4.2	4.1	2.3	0.0	0.0		839
2002		1.2	5.0	4.0	3.7	0.0	1.0		912
2003		0.0	3.1	1.3	0.9	0.0	0.0		321
2004									
Mean		2.6	4.9	4.4	3.7	3.5	3.1		1,343

YEAR	Monthly mean streamflow, in ft^3/s for C64 (Fish Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		0.0	5.5	4.1	5.2	5.7	7.9		1,725
1985		1.7	6.7	3.3	4.4	3.6	3.7		1,426
1986		0.5	6.4	5.4	5.8	5.1	8.3		1,908
1987		3.1	4.9	5.4	4.5	2.7	3.3		1,450
1988		4.2	5.4	6.0	3.7	1.2	0.7		1,281
1989		1.1	7.7	3.9	3.5	3.8	3.4		1,423
1990		5.6	4.7	5.7	4.5	4.4	3.2		1,704
1991		2.0	6.5	4.9	3.0	2.5	0.0		1,147
1992		4.2	5.5	3.9	4.7	2.4	0.0		1,253
1993		2.8	4.9	2.2	4.2	7.3	4.9		1,591
1994		5.9	4.2	4.8	1.8	0.0	0.0		1,007
1995		5.6	5.6	5.8	8.6	4.2	6.5		2,193
1996		3.7	6.4	3.4	5.2	5.8	8.0		1,970
1997		6.3	4.9	0.6	1.4	0.6	1.8		947
1998		1.0	1.2	0.0	2.9	6.5	5.4		1,030
1999		0.0	2.4	7.5	3.6	3.6	5.2		1,348
2000		2.3	9.1	6.4	8.0	7.5	1.6		2,117
2001		0.6	3.5	2.6	1.9	0.0	0.0		520
2002		5.9	5.9	3.0	2.4	0.0	0.5		1,066
2003		0.0	4.5	2.2	1.4	1.3	1.3		655
2004		0.7	4.0	4.4	2.4	0.0	0.0		697
Mean		2.7	5.2	4.1	4.0	3.3	3.1		1,355

YEAR	Monthly mean streamflow, in ft^3/s for C65 (Baroni Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		0.2	8.1	7.8	12.8	11.7	8.8		3,000
1985		6.8	11.3	9.8	6.9	2.2	7.1		2,657
1986		4.7	10.5	13.7	9.3	12.4	10.4		3,693
1987		8.6	9.6	10.1	3.3	1.9	0.9		2,074
1988		10.6	11.9	7.9	3.5	0.4	0.1		2,082
1989		9.8	11.2	11.4	6.7	4.5	2.2		2,767
1990		7.2	8.5	12.9	4.6	2.5	2.8		2,318
1991		7.6	13.6	12.8	5.7	4.0	0.0		2,645
1992		8.2	7.9	7.7	4.0	1.0	0.0		1,734
1993		10.3	11.8	9.0	14.4	9.3	9.8		3,909
1994		10.0	11.9	9.4	1.7	0.0	0.0		1,989
1995		4.0	7.0	9.7	5.5	10.0	9.6		2,767
1996		1.8	5.2	4.0	8.9	14.4	6.2		2,477
1997		0.0	2.8	1.6	8.4	3.6	5.3		1,324
1998		0.6	1.5	4.6	11.1	7.9	7.6		2,018
1999		2.4	3.6	6.1	10.6	11.2	8.3		2,558
2000		4.1	5.9	10.6	6.8	5.7	4.1		2,254
2001		4.0	10.6	5.5	0.1	0.0	0.0		1,228
2002		4.3	8.9	10.0	3.7	0.0	0.0		1,633
2003		4.7	8.2	8.5	8.9	6.3	3.4		2,430
2004		8.1	7.6	6.6	0.7	0.0	0.0		1,382
Mean		5.6	8.5	8.6	6.6	5.2	4.1		2,330

YEAR	Monthly mean streamflow, in ft^3/s for C66 (Cardelli Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		3.1	29.4	26.3	29.4	24.6	24.3		8,321
1985		15.1	30.4	22.4	4.6	1.7	4.4		4,752
1986		8.7	30.4	26.5	26.5	19.5	22.7		8,145
1987		25.3	35.7	17.9	3.2	1.3	0.4		5,063
1988		24.4	38.9	18.4	2.6	0.1	0.0		5,102
1989		31.7	36.1	31.7	9.9	3.0	3.3		6,984
1990		20.6	25.4	21.5	8.5	2.0	1.2		4,783
1991		16.1	31.1	30.1	8.6	0.4	0.0		5,207
1992		31.4	31.2	7.7	2.0	0.6	0.0		4,406
1993		31.4	45.4	27.6	34.8	7.4	3.4		9,095
1994		33.4	35.3	19.2	0.7	0.0	0.0		5,342
1995		6.7	13.5	13.8	20.8	7.6	4.4		4,055
1996		28.2	40.0	26.7	24.9	5.6	11.9		8,309
1997		27.7	39.0	26.9	25.2	5.7	11.8		8,250
1998		3.6	25.5	14.6	26.5	13.1	22.7		6,442
1999		10.7	29.6	28.4	29.4	19.0	16.3		8,094
2000		19.0	28.9	35.5	10.2	0.5	0.0		5,680
2001		24.2	32.4	13.0	0.0	0.0	0.0		4,203
2002		37.3	31.9	29.1	3.6	0.0	0.0		6,129
2003		15.0	20.2	24.2	5.8	1.2	0.0		4,004
2004		17.5	21.5	17.1	0.0	0.0	0.0		3,380
Mean		20.5	31.0	22.8	13.2	5.4	6.0		5,988

YEAR	Monthly mean streamflow, in ft^3/s for C67 (Quilici Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		1.8	9.0	10.6	11.3	9.5	11.0		3,226
1985		7.9	10.4	11.1	6.1	2.3	4.4		2,547
1986		6.2	9.2	7.5	5.9	8.2	8.6		2,761
1987		11.3	9.2	6.6	2.8	1.1	0.8		1,911
1988		7.6	10.0	8.5	2.1	2.4	0.4		1,871
1989		7.4	6.1	5.8	5.8	4.5	0.7		1,836
1990		7.4	7.7	8.5	5.8	1.8	1.9		2,005
1991		2.3	3.5	2.3	1.4	0.0	0.0		575
1992		3.3	3.2	2.3	0.1	0.0	0.0		535
1993		10.1	7.8	8.5	10.0	6.0	4.3		2,827
1994		8.9	6.7	6.5	0.7	0.0	0.0		1,375
1995		4.6	5.5	7.0	11.6	8.9	11.0		2,948
1996		5.3	9.1	12.2	11.1	9.1	5.5		3,179
1997		7.2	6.3	4.6	12.1	11.7	9.8		3,135
1998		1.0	5.0	4.6	14.3	10.4	8.0		2,638
1999		3.9	13.2	9.3	13.3	7.6	5.9		3,242
2000		5.6	9.3	12.0	7.7	2.7	0.5		2,292
2001		2.5	10.6	3.9	0.0	0.0	0.0		1,036
2002		2.7	9.8	8.1	1.5	0.0	0.0		1,339
2003		4.1	5.4	7.5	9.1	7.9	0.0		2,060
2004		2.5	7.9	6.9	0.0	0.0	0.0		1,042
Mean		5.4	7.9	7.4	6.3	4.5	3.5		2,113

YEAR	Monthly mean streamflow, in ft^3/s for C68 (Gee Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1985		1.7	2.9	1.3	1.0	0.5	2.6		607
1986		0.0	0.0	0.3	0.4	0.9	2.0		217
1987		1.2	1.9	1.2	1.5	0.0	0.0		354
1988		5.8	6.4	4.9	1.0	0.2	0.0		1,104
1989		6.4	5.8	4.3	1.1	0.6	0.0		1,094
1990		7.2	3.8	2.4	1.7	0.2	0.1		928
1991		5.4	4.4	2.4	1.8	0.3	0.0		861
1992		7.3	4.9	5.0	1.6	0.0	0.0		1,134
1993		6.8	8.2	4.5	2.4	4.0	2.6		1,729
1994		7.3	7.5	5.6	1.0	0.0	0.0		1,294
1995		7.3	7.1	5.1	2.3	3.0	1.7		1,594
1996		12.9	10.7	4.0	1.4	4.0	4.3		2,258
1997		3.3	16.8	18.3	4.4	4.3	1.5		2,943
1998		0.8	8.3	4.0	2.3	5.3	2.5		1,409
1999		0.2	3.0	3.2	1.0	5.2	4.6		1,048
2000		0.5	3.7	2.0	2.1	0.0	0.0		510
2001		4.3	6.0	3.3	0.0	0.0	0.0		822
2002		6.6	7.9	3.9	0.2	0.0	0.0		1,119
2003		2.6	4.3	2.8	0.5	0.4	0.0		637
2004		3.0	4.0	2.3	0.0	0.0	0.0		560
Mean		4.5	5.9	4.0	1.4	1.4	1.1		1,111

YEAR	Monthly mean streamflow, in ft^3/s for C69 (Koch Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		6.8	6.2	6.8	12.5	9.1	0.0		
1985		5.5	6.7	9.2	8.0	6.5	4.9		2,471
1986		2.6	6.2	8.6	6.4	8.3	8.4		2,450
1987		9.8	6.5	7.4	8.4	8.7	7.7		2,936
1988		10.2	11.1	10.9	7.7	6.2	5.0		3,089
1989		4.1	6.3	6.7	8.2	6.1	5.2		2,224
1990		5.4	5.1	7.5	5.8	4.1	4.9		1,977
1991		7.9	7.1	7.7	6.8	5.9	0.0		2,148
1992		6.8	7.6	6.6	5.0	3.1	0.0		1,763
1993		1.1	6.3	1.6	6.0	8.4	5.6		1,762
1994		6.0	6.1	6.8	1.8	0.0	0.0		1,248
1995		0.0	0.0	3.0	6.7	6.0	6.3		1,327
1996		0.0	2.4	7.2	7.2	5.7	1.9		1,485
1997		1.5	6.1	6.0	9.3	7.6	6.7		2,255
1998		0.0	1.7	3.3	5.8	10.3	6.1		1,648
1999		0.0	3.8	4.8	5.1	7.5	4.3		1,554
2000		2.8	7.6	11.9	8.7	4.6	1.1		2,224
2001		5.5	8.4	3.3	0.0	0.0	0.0		1,042
2002		14.1	19.6	9.7	2.3	0.0	0.0		2,767
2003		7.9	8.0	7.0	3.5	4.5	1.9		1,984
2004		8.0	9.7	7.9	1.0	0.0	0.0		1,611
Mean		5.0	6.8	6.9	6.0	5.4	3.3		1,998

YEAR	Monthly mean streamflow, in ft^3/s for C70A (Houghman and Howard Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1985		6.5	3.7	2.8	0.3	0.4	0.0		826
1986									
1987		0.7	0.4	0.0	0.9	0.1	0.0		127
1988		5.4	3.9	3.8	1.7	2.4	0.1		1,045
1989		2.1	0.7	2.9	5.3	3.0	3.6		1,069
1990		2.8	3.2	5.6	0.3	0.8	0.7		797
1991		3.7	4.3	5.4	1.2	4.4	0.0		1,151
1992		5.3	7.3	4.7	3.9	0.4	0.0		1,309
1993		4.2	2.8	3.1	7.3	4.4	4.3		1,572
1994		6.5	6.1	6.1	1.7	0.0	0.0		1,226
1995		1.9	3.1	4.3	3.5	1.8	2.1		1,007
1996		4.1	2.7	5.3	1.5	1.9	3.0		1,114
1997		2.5	13.9	1.3	4.2	5.9	4.9		1,998
1998		2.0	1.7	4.5	5.7	6.8	4.3		1,517
1999		3.7	6.2	6.7	9.1	8.0	4.3		2,303
2000		1.1	5.2	8.0	6.4	7.5	2.9		1,885
2001		0.2	4.2	8.7	3.0	0.3	0.0		993
2002		4.7	4.8	5.9	4.7	0.4	0.0		1,239
2003		3.5	4.0	4.6	6.2	3.8	4.3		1,600
2004		3.5	6.9	7.0	5.6	3.2	0.0		1,591
Mean		3.4	4.5	4.8	3.8	2.9	1.8		1,283

YEAR	Monthly mean streamflow, in ft^3/s for C71 (Upper Buckland Ditch)								Total Acre-Feet
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
1984		0.0	24.0	23.2	17.6	15.3	12.4		5,619
1985		22.0	24.2	17.4	11.2	6.4	12.4		5,651
1986		5.3	24.1	20.3	11.5	20.8	21.7		6,279
1987		20.7	20.9	15.6	6.6	2.4	0.5		4,035
1988		18.0	23.9	22.0	8.2	0.3	0.5		4,404
1989		22.1	24.9	21.8	18.4	6.5	4.2		5,915
1990		23.8	27.9	23.7	9.4	3.2	1.7		5,419
1991		18.8	18.0	19.9	12.9	4.2	0.0		4,457
1992		18.0	19.7	10.4	2.9	0.4	0.0		3,104
1993		24.3	26.1	24.5	23.7	14.6	7.6		7,306
1994		26.1	21.7	16.1	3.3	0.0	0.0		4,051
1995		13.0	18.8	13.1	16.8	21.9	17.3		6,123
1996		13.4	20.6	15.8	19.3	13.6	15.0		5,920
1997		13.9	38.8	45.9	14.2	23.8	14.3		9,131
1998		0.0	0.0	32.2	39.8	17.6	18.2		6,528
1999		0.0	31.8	21.5	23.5	16.5	9.0		6,226
2000		30.9	20.0	27.1	9.3	0.3	0.0		5,270
2001		21.3	27.8	13.4	0.0	0.0	0.0		3,772
2002		23.1	33.9	25.5	7.7	0.0	0.0		5,446
2003		14.4	31.4	35.8	10.0	6.7	0.0		5,942
2004		27.6	37.9	21.8	4.1	0.0	0.0		5,518
Mean		17.0	24.6	22.2	12.9	8.3	6.4		5,529

YEAR	**Monthly mean streamflow, in ft^3/s for C72 (Lower Buckland Ditch)**								**Total Acre-Feet**
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	
1984		0.0	16.2	16.3	11.3	9.2	7.6		3,677
1985		20.1	20.9	12.3	8.0	2.8	7.9		4,348
1986		3.1	19.0	11.2	7.2	10.9	13.8		3,948
1987		12.7	16.2	11.2	4.0	0.1	0.0		2,673
1988		13.4	12.8	11.4	1.4	0.0	0.0		2,355
1989		13.0	13.7	15.0	11.1	2.7	1.2		3,425
1990		13.8	19.1	14.0	4.9	0.7	0.0		3,173
1991		11.4	11.2	12.5	7.8	0.0	0.0		2,588
1992		9.7	11.7	3.9	1.9	0.0	0.0		1,641
1993		12.4	14.6	12.0	11.5	5.5	3.5		3,607
1994		10.5	9.3	5.3	0.8	0.0	0.0		1,559
1995		7.7	13.4	8.2	8.2	8.5	8.5		3,308
1996		9.2	18.9	7.3	7.7	5.9	7.3		3,420
1997		7.8	15.5	18.4	11.3	15.4	9.2		4,702
1998		7.7	2.0	6.0	10.8	7.7	13.8		2,885
1999		5.6	14.1	6.0	9.7	8.8	3.8		2,929
2000		14.2	6.9	8.5	4.8	0.0	0.0		2,069
2001		15.4	6.4	3.6	0.0	0.0	0.0		1,527
2002		12.7	11.3	14.4	2.4	0.0	0.0		2,455
Mean		10.549	13.3	10.4	6.6	4.1	4.0		2,963