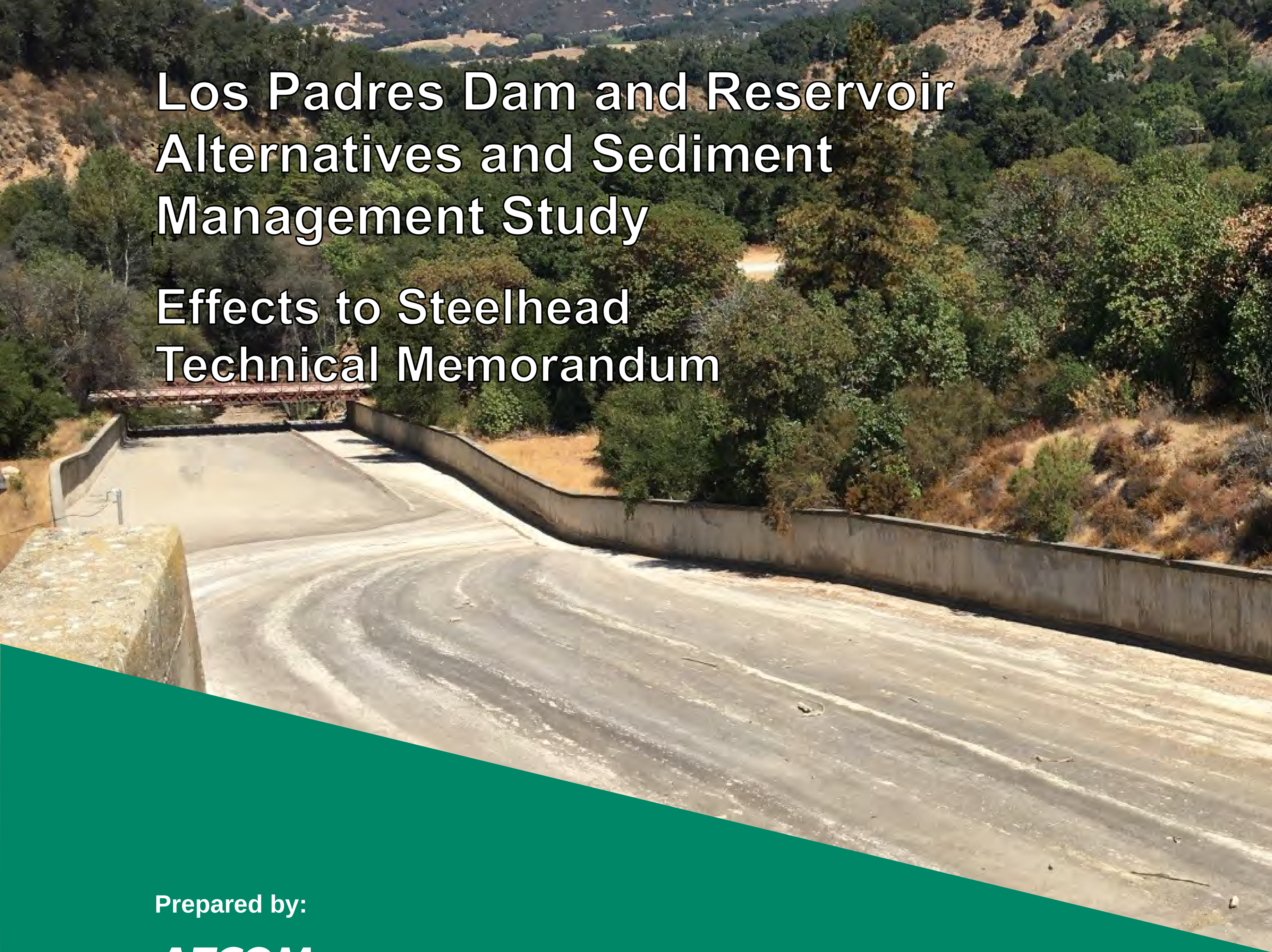
Los Padres Dam and Reservoir Alternatives and Sediment Management Study

Effects to Steelhead Technical Memorandum



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Monterey Peninsula Water Management District
In cooperation with
California American Water

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List of Acronyms and Abbreviations

AF	acre-feet
AFY	acre-feet per year
Alley & Associates	D.W. Alley & Associates
ASR	aquifer storage and recovery
BESMo	University of British Columbia’s one-dimensional morphodynamic sediment transport model
BGS	behavioral guidance system
°C	degrees Celsius
Cal-Am	California American Water
CD	product of concentration and duration
CDFG	California Department of Fish and Game (now CDFW)
CDFW	California Department of Fish and Wildlife
CDO	cease and desist order
cfs	cubic feet per second
cm	centimeter
CRBHM	Carmel River Basin Hydrologic Model
DPS	Distinct Population Segment
°F	degrees Fahrenheit
FL	fork length
FNU	formazin nephelometric units
FR	Federal Register
FSC	floating surface collector
ft^2	square feet
FWC	floating weir collector
IFIM	instream flow incremental methodology
LP Alternatives Study	Los Padres Dam and Reservoir Alternatives and Sediment Management Study
LPD	Los Padres Dam
LPR	Los Padres Reservoir
mg-hr/L	milligrams per hour per liter
mg/L	milligrams per liter
mm	millimeters
MPWMD	Monterey Peninsula Water Management District
NAVD88	North American Vertical Datum of 1988
NDEP	Nevada Division of Environmental Protection
NMFS	National Marine Fisheries Service
NSE	Nash-Sutcliffe Efficiency
pcf	pounds per cubic foot
PIT	passive integrated transponder
RM	river mile
S-CCC	South-Central California Coast
SEV	severity of ill effect
TM	Technical Memorandum
TRC	Technical Review Committee
UBC	University of British Columbia

1. Introduction

This is one in a series of Technical Memoranda (TMs) developed as part of the Los Padres Dam and Reservoir Alternatives and Sediment Management Study (LP Alternatives Study). It is the deliverable for Task 3 of the LP Alternatives Study and has been developed in consideration of preceding TMs, including the Study Preparation TM (AECOM 2017a), the Draft Alternatives Descriptions TM (AECOM 2017b), the Sediment Characterization TM (AECOM 2018), the Sediment Effects TM (Balance Hydrologics and UBC Geography 2019), and the Fish Passage Feasibility Report (HDR et al. 2021).

1.1 Purpose and Scope

The purpose of this TM is to present analysis of effects to steelhead relevant to the dam and reservoir alternatives currently described for the LP Alternatives Study in the Draft Alternatives Descriptions TM (AECOM 2017b). The analysis can be used to inform further development of those alternatives (in the upcoming Task 4, Alternatives Development) and then later to evaluate the more-developed alternatives. Potential effects to steelhead and their habitats resulting from the alternatives described, in the context of the South-Central California Coast (S-CCC) steelhead population, are evaluated and summarized. The analysis focuses on habitat extent, passage through the reservoir area, passage over the dam, and water quality in the reservoir and downstream; and summarizes effects to steelhead of varying levels of water supply and sediment transport in the river, and potential changes to steelhead habitats. A draft TM was provided prior to Technical Review Committee (TRC) Meeting No. 2b and was discussed at the meeting. This TM has been revised based on written comments received from the TRC after the meeting.

1.2 Overview of Steelhead in Carmel River Watershed

Previous reports and studies of historical and current abundance, distribution, and occurrence of steelhead in the Carmel River watershed were summarized in the Los Padres Dam and Reservoir Alternatives and Sediment Management Study, Study Preparation TM (AECOM 2017a). The following sections provide a brief overview of steelhead in the Carmel River Watershed.

Steelhead found in the Carmel River watershed (Figure 1) belong to the S-CCC Distinct Population Segment (DPS), which is listed as threatened under the Endangered Species Act (62 Federal Register [FR] 43937, 71 FR 834). The Carmel River once contained the largest steelhead run in the range of the S-CCC steelhead DPS (NMFS 2012). The Carmel River population of S-CCC steelhead is considered an important population within the DPS because it likely acts as a source population for the smaller coastal drainages, which are not considered viable by the National Marine Fisheries Service (NMFS) and may not be able to persist without straying from the Carmel River population. Moreover, the Carmel River Watershed is considered unique from the other watersheds supporting the DPS in that the Carmel River population possesses both interior and coastal population attributes. These attributes may provide more resistance to environmental variability and may aid in maintaining genetic diversity. For these reasons, the Carmel River population of S-CCC steelhead is considered highly valuable compared to other populations within the DPS (NMFS 2013).

The Carmel River Watershed contains abundant suitable habitat for S-CCC steelhead. Access to much of this habitat is currently influenced by the presence of Los Padres Dam (LPD), where a trap-and-haul facility provides upstream passage, and a bypass pipe and the dam's spillway provide downstream passage. The watershed contains extensive (>50 miles) steelhead spawning and rearing habitat in the mainstem and tributaries (MPWMD 2004) (Figure 1). However, portions of the Carmel River continually dry back in the summer months, which limits available rearing habitat. Ohms et al. (2021) developed an inferred dry map of the Carmel River watershed based on records of Monterey Peninsula Water Management District (MPWMD) fish rescue relocations (Figure 2). The inferred dry map was generated by analyzing MPWMD's notes on when fish rescues occurred and assuming that sections of streams listed as rescue sites subsequently dried up. The map was later adjusted based on gauge data and electrofishing data if either source indicated that surface flow was retained. Ohms et al. (2021) concluded that the lower portion of the Carmel River consistently dried up in all but the wettest years, likely due to groundwater pumping, and that portions of Reach 3 also consistently go dry; these dry sections expand during drought years.

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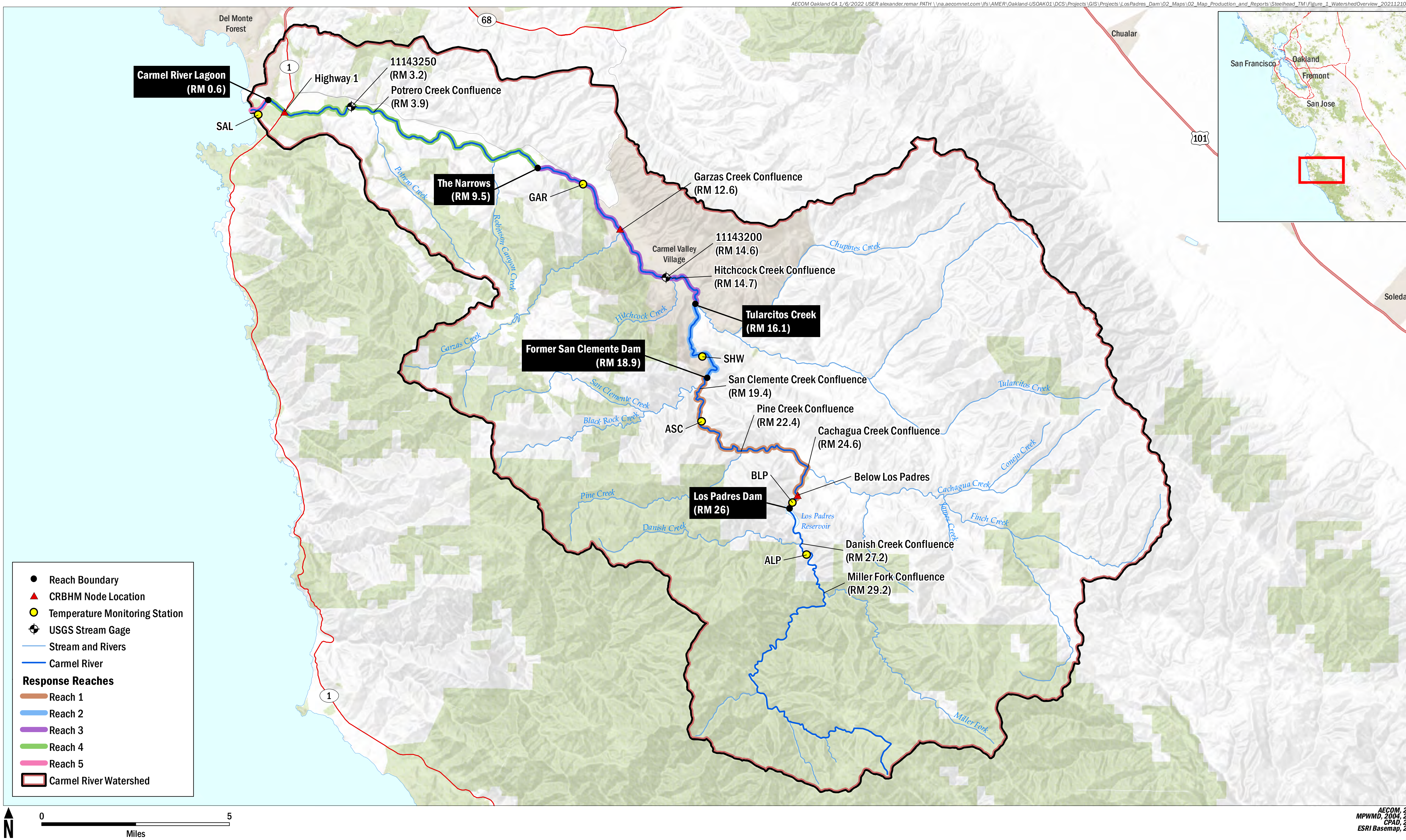


AECOM, 2021
MPWMD, 2004, 2014
CPAD, 2020
ESRI Basemap, 2021

AECOM
Monterey Peninsula Water Management District
Los Padres Alternaitves Study

FIGURE 1
Carmel River Watershed Overview

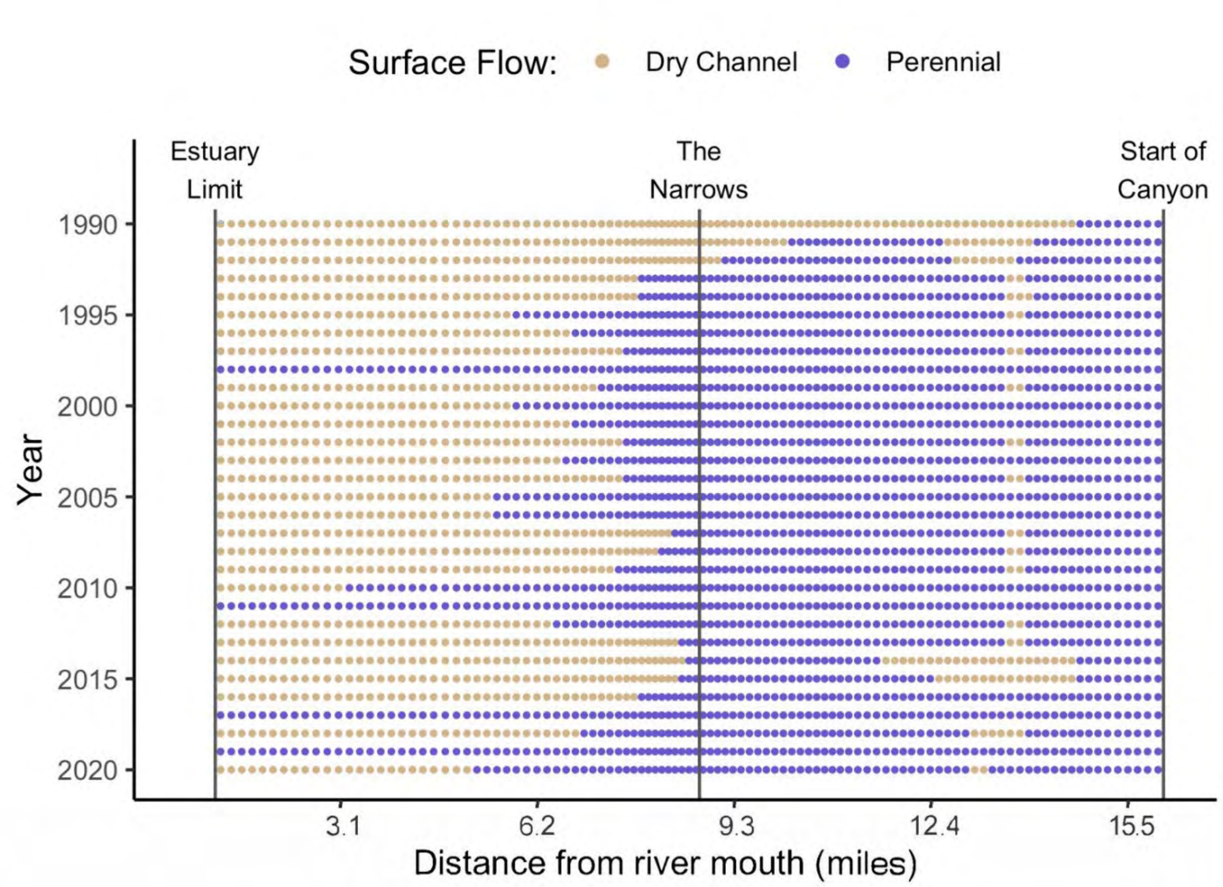


Figure 2 Map of the Maximum Extent of Dry Channel Each Year, as Inferred from Records of Fish Relocations

Source: Provided by D. Boughton (revised from Ohms et al. 2021), scale converted by AECOM

1.2.1 Historical Steelhead Use of Watershed

The historical population of S-CCC steelhead in the Carmel River Watershed prior to the construction of San Clemente Dam (built in 1921) and LPD (built in 1949) was estimated to be between 1,500 and 8,000 adults annually (Becker et al. 2010). Other qualitative estimates place the pre-dam population closer to 12,000 (Snider 1983). In their Biological Opinion for the Carmel River Reroute and San Clemente Dam Removal Project, NMFS (2012) estimated that habitat in the Carmel River Basin could support roughly 4,000 adult steelhead annually—with the habitat upstream of Los Padres Reservoir (LPR) potentially supporting around 2,000 fish, the habitat between Los Padres and San Clemente reservoirs potentially supporting 1,000 fish (Response Reach 1), and the habitat downstream of San Clemente Dam potentially supporting around 1,000 fish (Response Reaches 2–5). A 1986 Biological Assessment for the Carmel River (as cited in Becker et al. 2010) indicated that, "above LPR the steelhead have access to 14.4 miles of the Carmel River and the tributaries, all of which contain large amounts of spawning and rearing habitat."

1.2.2 Current Steelhead Use of Watershed

Adult steelhead return annually to the Carmel River watershed; however, large fluctuations in abundance occur each year. Annual adult steelhead counts at the LPD fish trap range from 0 to 558 fish (Figure 2-37, Number of Adult Steelhead Counted at the LPD [1949 – 2017], in AECOM 2017a). Several of the years in which no adult steelhead were captured in the Los Padres fish trap were drought years (1976 and 1977, the early 1990s, and 2014 through 2016) during which the lagoon was not open or open only for brief periods. In 2019, 126 adult steelhead were counted at LPD. The majority of steelhead spawning habitat downstream of LPD occurs in Reach 3 (MPWMD 2004).

The California Department of Fish and Wildlife (CDFW) and MPWMD survey data on juvenile steelhead density at annually sampled index sites in the Carmel River also show large annual fluctuations, periods of juvenile steelhead absence during droughts, and a generally declining trend in juvenile abundance from 2000 to 2013 (MPWMD 2015). The decline of steelhead in the watershed was likely due in part to the presence of Old Carmel River Dam, San Clemente Dam, and LPD (Figure 1) (which have been partial barriers to historic spawning and rearing habitat); streamflow reductions due to water diversion from wells downstream of San Clemente Dam; and habitat fragmentation and degradation (MPWMD 2004; NMFS 2012). In 2016, the removal of San Clemente Dam enhanced the ability of both upstream and downstream migrant steelhead to move through that reach of the river. MPWMD estimates that LPD limits access to about 50 percent of the spawning habitat for the Carmel River and 42 percent of rearing habitat (MPWMD 2004, as cited in NMFS 2012). Removal of this dam would be expected to reestablish natural river processes throughout approximately 27 miles of critical habitat for steelhead in the Carmel River. It would have a number of benefits for the Carmel River steelhead population, including enhanced downstream passage conditions for juveniles, kelts, and smolts; and upstream passage for juveniles and adults. It would improve juvenile and adult mobility in the dam removal project area, as well as providing access to a greater range of habitat (NMFS 2012).

Juvenile steelhead monitoring efforts in the Carmel River conducted by Boughton et al. (2020) from 2017 through 2019 evaluated juvenile steelhead distribution throughout four different reaches of the Carmel River: the valley portion of the mainstem (Tularcitos Creek to the estuary); the canyon portion of the mainstem (LPD to Tularcitos Creek); the upper watershed upstream of LPR; and the set of southern tributaries draining the northernmost portion of the Santa Lucia Mountains (Table 1). Results indicate that juvenile steelhead densities were essentially the same throughout the survey reaches in 2017 and 2018 and ranged from approximately 20,000 to 30,000 fish per reach. Juvenile steelhead abundances increased each year in the canyon and valley sectors of the Carmel River by 20 to 150 percent and were estimated to be 42,000 and 52,000, respectively (Boughton et al. 2020). Boughton et al. (2020) also found high densities of juvenile steelhead upstream of LPR and in the southern tributaries after a period of prolonged drought, indicating that these areas likely provide drought refugia. Ohms et al. (2021) found that continued dewatering of the lower Carmel River is a detriment to juvenile steelhead rearing and that average fish production in Reaches 1 through 3 are nearly 4.5 times higher than in Reach 4.

Although available spawning habitat and rearing habitat (especially in relation to instream flows) are not well documented upstream of LPD, limited information suggests that even during periods of low flow, the Carmel River upstream of LPD can support high densities of *O. mykiss*. For example, in July 1994 the California Department of Fish and Game (CDFG) (1995) sampled upstream of LPR and estimated densities of approximately 4,000 *O. mykiss* per mile when streamflow was less than 1 cubic foot per second (cfs). CDFG estimated similar densities of approximately 4,700 fish per mile when streamflow was much higher (close to 11 cfs) the year prior, in July 1993 (CDFG 1994). Population estimated by CDFG (1995) over a 5-year period from 1989 to 1994 suggest that the *O. mykiss* population upstream of LPR was stable during that period.

The life history strategy of steelhead upstream of LPR is also not well understood. LPD and LPR are partial barriers to both upstream and downstream steelhead passage, so it is possible that the *O. mykiss* population upstream of LPD expresses a resident life history strategy more frequently than it would in the absence of the dam. In 2019 Boughton et al. (2020) captured and installed passive integrated transponder tags (PIT tags) in 345 downstream migrants moving from the upper watershed toward LPR. Boughton et al. (2020) reported that about 75 percent of downstream migrants did not pass through the reservoir and could either be adopting an adfluvial life-history or suffering predation in the reservoir. Observations of large (> 250 millimeters [mm] fork length [FL]) *O. mykiss* upstream of the reservoir led CDFG (1995) to assume the potential of an adfluvial life history in the upper Carmel River watershed, where *O. mykiss* are obtaining substantial food resources in the reservoir.

Table 1 Summary of Juvenile Rearing Habitat Distribution in the Carmel River Watershed

Reach[1]	Estimated Age 1+ Rearing Habitat (ft^2)	Proportion of Total Available Rearing Habitat (Percent)	Rearing Density (Low, Moderate, High)[2]
Response Reach 1 (at 5 to 16 cfs)	590,553	23	High
Response Reach 2 (at 5.6 cfs)[3]	284,787	11	Moderate
Response Reach 3 (at 5.6 to 8.5 cfs)	629,562	24	High
Response Reach 4	Seasonally dry	0	Low
Response Reach 5	No data	No data	High[4]
Total in mainstem Carmel River downstream Los Padres Dam	1,469,093	57	
Tributaries to Carmel River downstream Los Padres Dam[5,6]	180,421	7	Moderate to high
Total downstream Los Padres Dam	1,649,514	64	
Carmel River and tributaries upstream of Los Padres Dam[6]	937,623	36	Low to high
Total in watershed	**2,587,137**		

Notes:

1 Response reaches are: 1) the inter-dam reach between Los Padres Dam and the former San Clemente Dam; 2) San Clemente Dam to Tularcitos Creek; 3) Tularcitos Creek to the Narrows; 4) from the Narrows to the Carmel River lagoon; and 5) from the lagoon to the ocean (Figure 1).

2 Based on three-pass MPWMD electrofishing surveys at index sites (MPWMD 2015): low (< 0.50 fish/foot), moderate (0.51 to 0.75 fish/foot), high (>0.76 fish/foot).

3 Does not include rearing habitat that was previously inundated by the former San Clemente Reservoir.

4 Productive rearing observed (Alley & Associates 2014).

5 Survey of tributaries downstream of Los Padres Dam did not include potential habitat in tributaries, including Pine, Tularcitos, Garzas, and Robinson Canyon Creeks.

6 Density data based on Snider (1983), as cited in MPWMD (2004).

cfs = cubic feet per second
ft^2 = square feet
MPWMD = Monterey Peninsula Water Management District

Sources: Alley & Associates 2014, MPWMD 2004, MPWMD 2015, Snider 1983

1.3 Overview of Alternatives and Sediment Management Options

Full descriptions of the alternatives, sediment management options, and combinations of alternatives and options evaluated in this TM are provided in the Draft Alternatives Descriptions TM (AECOM 2017b) and listed in Table 2 below.

Table 2 Summary of Alternatives and Options Evaluated

Alternative/Option	Description
1	Los Padres Dam Remains (No Sediment Management)
2	Dam Removal
3	Restore Reservoir Capacity
4	Storage Expansion
SM-1	Periodic Sediment Removal to Offsite Disposal Site
SM-2	Periodic Sediment Removal and Placement Downstream
SM-3	Sluicing Tunnel

2. Approach

To assess the biological feasibility of each alternative, the following impacts associated with the implementation of the alternatives and sediment management options were evaluated: short-term impacts of implementing the alternative, long-term effects of the alternative on habitat availability, passage from the ocean through the reservoir area, water quality in the reservoir, and quantity and quality of water and sediment releases from the reservoir. This chapter outlines the key response variables to be evaluated, along with the existing information used to determine how each alternative and sediment management option for the LPD and LPR could potentially affect steelhead in the Carmel River watershed.

The following reports were used extensively for this evaluation:

- Los Padres Dam and Reservoir Alternatives and Sediment Management Study, Study Preparation TM (AECOM 2017a)
- Los Padres Dam and Reservoir Alternatives and Sediment Management Study Draft Alternatives Descriptions TM (AECOM 2017b)
- Fish Passage Feasibility Report (Draft), Los Padres Dam Fish Passage Study (HDR et al. 2021)
- Los Padres Dam and Reservoir Alternatives and Sediment Management Study, Sediment Effects TM (Balance Hydrologics and UBC Geography 2019)
- Assessing Instream Flow Requirements for Steelhead in the Carmel River, California (Normandeau 2019)
- Overview of the Development and Calibration of the Carmel River Basin Hydrologic Model (CRBHM). Draft Tech Memo (Christensen et al. 2021)
- Carmel River Instream Flow Habitat Time Series Memorandum (Normandeau 2021)
- Carmel River Steelhead Fishery Report (Boughton and Ohms 2018)
- Carmel River Steelhead Fishery Report (Ohms and Boughton 2019)
- Carmel River Steelhead Fisheries Report 2020 (Boughton et al. 2020)
- Carmel River Fisheries Report 2021 (Ohms et al. 2021)

2.1 Bedload Sediment Transport

The downstream transport of sediment currently stored in reservoir deposits can affect downstream steelhead habitat and channel morphology as both suspended sediment and bedload. This evaluation considers the potential effects of suspended sediment on steelhead migration, and of rearing and bedload sediment on steelhead habitat, under each alternative.

Bedload supply and transport are vital to the creation and maintenance of functional aquatic habitat. Natural river dynamics include transportation of coarse sediment (e.g., sand, gravel, cobble, and boulder) downstream. Natural sediment pulses that result from heavy precipitation events are incorporated by stream and river processes into spawning beds, gravel bars, side channels, pools, riffles, and floodplains that provide habitat and support food chains of steelhead (and other aquatic species). These periodic inputs and movements of coarse sediment are necessary for the long-term maintenance of aquatic habitats. Steelhead evolved to depend on continued sediment delivery to provide substrate suitable for spawning and early rearing; and on access to floodplains that provide rearing habitat and velocity refugia during high winter flows.

Balance Hydrologics and UBC Geography (2019) used a morphodynamic sediment transport model (BESMo) to assess the effects of sediment transport under different alternative and sediment management options. Channel evolution modeling was completed to evaluate potential downstream effects related to sediment supply associated with four different potential future sediment management scenarios at LPD. Modeling was completed using the one-dimensional BESMo model (Müller and Hassan 2018), a model developed and written by scientists at the University of British Columbia. BESMo was originally developed to investigate how bedload supply pulses to gravel-bed mountain streams evolve in time and space, through coupled bed elevation and bed surface sediment texture responses. The model was used to simulate erosion, deposition, and transport of sediment in the Carmel River downstream of

LPD, including future conditions where sediment from LPR is transported into the Carmel River. The predicted flow and sediment concentrations leaving the reservoir were used as input into the BESMo model. The three BESMo scenarios considered in this steelhead effects evaluation are:

1. **No Action Simulation:** The No Action Simulation makes no change to the present operation or configuration of LPD or LPR, and as a result includes no bedload supply from the contributing watershed upstream of LPD to the downstream mainstem Carmel River. This scenario applies to Alternative 1, Alternative 3, and Alternative 4.

2. **Uncontrolled Supply Simulation:** In the Uncontrolled Supply Simulation, sediment accumulated in LPR is rapidly transported to the downstream mainstem Carmel River according to sediment evacuation functions developed with data from similar types of previously completed bypass projects. This scenario applies to Alternative 2, assuming that all the accumulated bedload sediment is available for transport immediately following dam removal.[1]

3. **Pulsed Supply Simulation:** In the Pulsed Supply Simulation, sediment accumulated in LPR and the background historical supply is bypassed to the downstream mainstem Carmel River, according to the magnitude of individual flood events, through a bypass tunnel. This scenario applies to the Periodic Sediment Removal and Placement Downstream (SM-2) and Sediment Sluicing Tunnel (SM-3) Sediment Management Options.

To understand the effect of alternatives on steelhead habitat related to expected changes in sediment transport processes, changes to channel morphology were assessed based on model results. The evaluation used analysis of the BESMo results, combined with knowledge of habitat requirements of steelhead, to assess how changes in bed elevation, substrate composition, and geomorphic processes would affect steelhead habitat (e.g., pool habitat, spawning gravel, floodplain connectivity, and winter refuge habitat).

2.2 Suspended Sediment

Elevated suspended sediment concentrations may affect fish directly by changing their behavior, causing physiological stress, clogging or abrading the gills, and/or preventing fish from foraging efficiently. As the transported sand and fine sediment settles on the streambed, it can reduce the survival of incubating eggs and developing alevins in salmonid redds through reduced oxygenation of intergravel flow. Based on a review of the scientific literature, the most commonly observed effects of suspended sediment on salmonids include (1) avoidance of turbid waters in homing adult anadromous salmonids, (2) avoidance or alarm reactions by juvenile salmonids, (3) displacement of juvenile salmonids, (4) reduced feeding and growth, (5) physiological stress and respiratory impairment, (6) damage to gills, (7) reduced tolerance to disease and toxicants, (8) reduced survival, and (9) direct mortality (Newcombe and Jensen 1996). Information on both concentration and duration of suspended sediment was used in this evaluation of the potential severity of its effects on salmonids, following the approach detailed by Newcombe and Jensen (1996).

Under the proposed alternatives and sediment management options, dredging and excavation of reservoir sediment would cause local increases in suspended sediment in the reservoir. Because the accumulated Zone 1 and Zone 2 sediments would be removed prior to dam removal (AECOM 2017b), sediment management could be conducted as a stand-alone action or prior to dam removal. A sluice tunnel could, if used to flush accumulated reservoir sediment, involve releasing large quantities of fine sediment (silt, organic matter, and fine sand) from the sediment accumulated in LPR into the Carmel River. Thus, the sluicing tunnel option (SM-3) is the most likely of the proposed alternatives and options to affect in-stream fish populations from elevated suspended sediment, whether intended solely to manage accumulated sediment or to prepare for dam removal.

[1] Note that the Alternatives Description TM assumes that Zone 1 and Zone 2 sediment would be removed in Alternative 2 via a sediment management option. Accordingly, the analysis of Alternative 2 in this Steelhead Effects TM focuses on the longer-term effects of the bedload transport resulting from the implementation of Alternative 2. Shorter-term effects from transport of fine sediment are discussed as part of the effects from the Sediment Management Options.

Although the BESMo does not predict suspended sediment concentrations or durations, suspended sediment rating curves were developed concurrently with the BESMo (Balance Hydrologics and UBC Geography 2019) and were used by AECOM to develop an approximation of potential suspended sediment concentrations downstream of LPD. A spreadsheet analysis of available flows and sediment rating curves was used to estimate potential suspended sediment concentrations and durations, using the daily flow hydrograph from the CRBHM for Alternative 2. A CRBHM node downstream of the LPD spillway, fish trap, and low-level outlet return flow channel, which captures all flows that pass LPD and LPR, was selected as the one most closely representing inflow to LPR from the data available to AECOM (Figure 1). As in the bedload transport analysis in Balance Hydrologics and UBC Geography (2019), the daily hydrograph was analyzed to find storm events (flows greater than 100 cfs for a minimum of 2 days). A peaking factor (Table 3-3 of Balance Hydrologics and UBC Geography 2019) was then applied to the average daily flow on the day of the storm peak to simulate the increased sediment transport resulting from the peak flow, from which the peak sediment concentration can be derived. In addition to the peaking factor, the hydrograph was screened for flows between 500 and 5,000 cfs to simulate the sluicing operation; no flow was passed below 500 cfs and any flows above the range were limited to 5,000 cfs. This resulted in a daily hydrograph representing flows released through the sluice tunnel over the flow record.

The suspended sediment rating curve for Robles del Rio for the episodic condition[2] (Table 2-1 and Figure 2-5 of Balance Hydrologics and UBC Geography 2019) was used to translate the flows in the sluice tunnel hydrograph into sediment transport in tons per day, and then into sediment concentrations in milligrams per liter (mg/L), to represent a sluicing condition. The resulting maximum suspended sediment concentration over the record was just under 1,300 mg/L, and occurrences within various concentration ranges are shown on Figure 3. These concentrations, because they are derived from suspended sediment data collected in the river, are more like background levels expected to be produced by the watershed; they do not describe the conditions that could occur during a flushing event, where fine sediment is intentionally transported through the sluice tunnel.

Because a major flushing event is expected to be able to discharge all or most of the fine sediment from the reservoir, the total suspended transport for individual storm events was compared to the total amount of sediment in Zone 1 of the reservoir. As described in AECOM 2017b, Zone 1 contains primarily silts, organic matter, and fine sand. Boring logs for cores in Zone 1 recorded dry densities from 27.4 to 50.9 pounds per cubic foot (pcf), with an overall depth-averaged dry density of 44.0 pcf. Moisture as a percent of dry weight varied between 77.4 and 177.5 percent, with an overall depth-averaged percent of 93.2. AECOM (2017b) also estimated a total volume of Zone 1 material of 340 acre-feet (AF). Using the overall average dry density and percent moisture, this volume is equal to approximately 197,000 tons of sediment in Zone 1.

As a comparison, the largest event-based cumulative sediment transport based on the episodic rating curve was approximately 44,000 tons, over the period from February 6 to February 10, 1998, with flows ranging from 1,000 to 5,000 cfs. If a major flushing event transported the contents of Zone 1, the sediment concentrations would be expected to increase significantly over the episodic background conditions.

The analysis then assumed that the largest storm event in the analysis record would transport all the sediment in Zone 1, and smaller events would transport less than the full amount of sediment in Zone 1. The largest storm event was selected based on the estimated cumulative sediment transport (the event of February 6 through 10, 1998), and the coefficient of the suspended sediment rating curve was adjusted so that the cumulative transport for the storm event equaled the total sediment weight in Zone 1. This resulted in a nearly 4.5-fold increase in suspended sediment transport. The resulting maximum suspended sediment concentration over the record was nearly 5,800 mg/L, and occurrences within various concentration ranges are shown on Figure 3. Figure 4 shows the suspended sediment concentrations over time during the winter of water year 1998, which includes the largest storm event.

[2] Only data points supporting the fit of the episodic suspended sediment transport rating curve are shown on Figure 2-5 of Balance Hydrologics and UBC Geography (2019). Data points supporting the chronic suspended sediment transport rating curve are not shown on Figure 2-5, so the chronic rating curve was not used in this analysis.

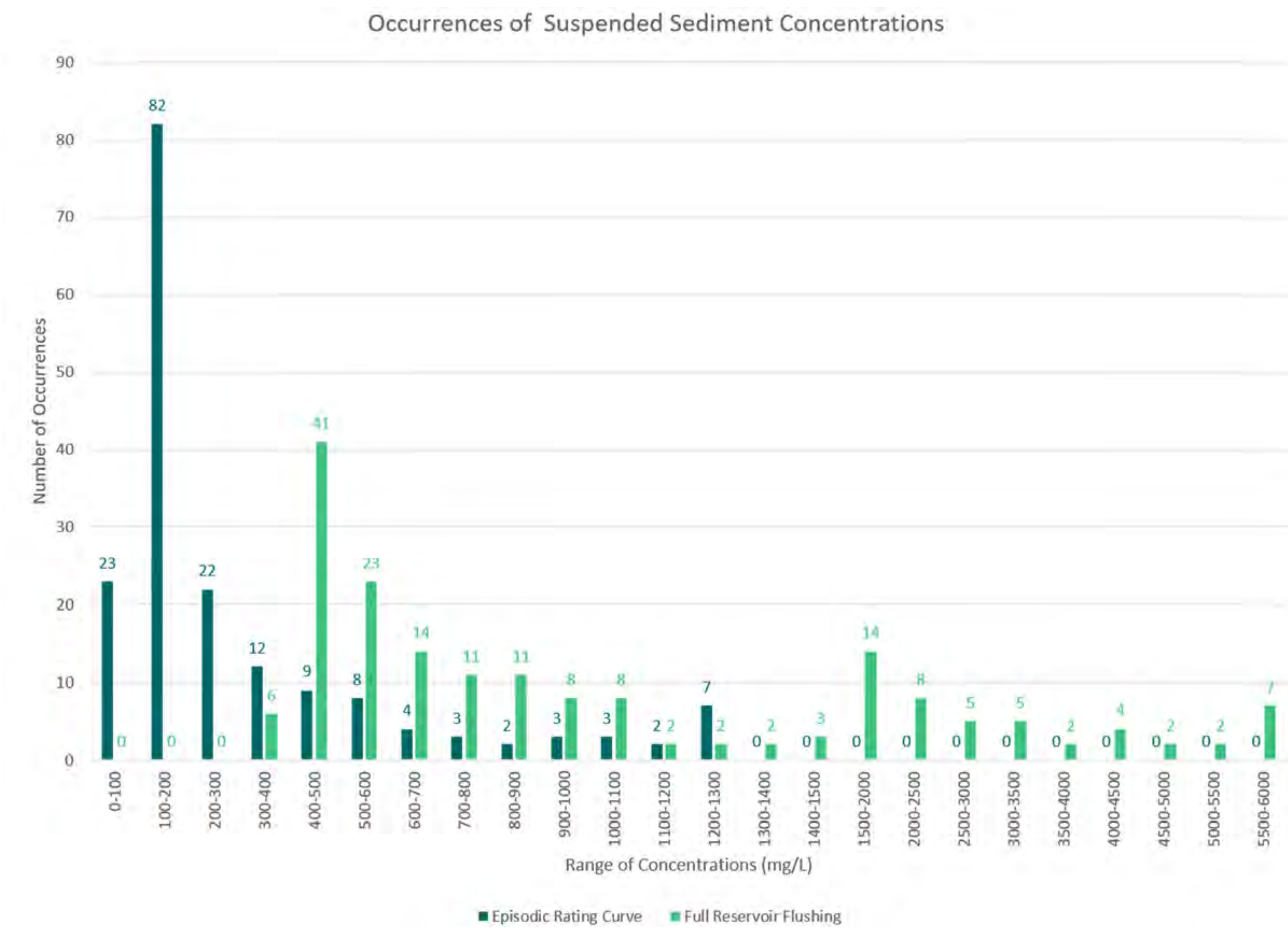


Figure 3 Occurrences of Suspended Sediment Concentrations

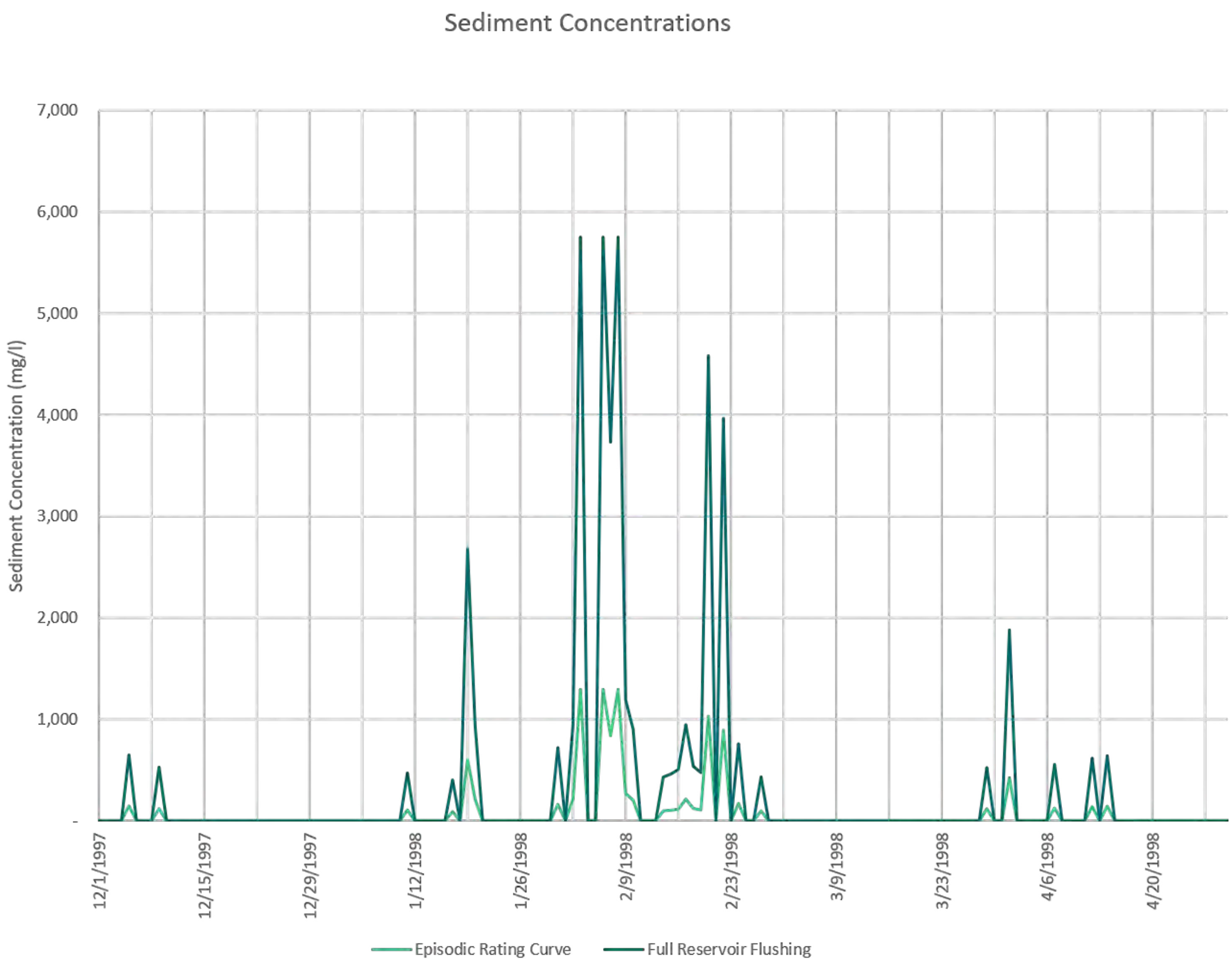


Figure 4 Sediment Concentrations During Winter of Water Year 1998

This review of suspended sediment concentrations is based on a simplified simulation of sluicing events and how those would translate into sediment transport. The analysis did not include modeling sediment transport from the reservoir or in the river channel. If the sluice tunnel option is selected for further development, sediment transport modeling of the sluicing operation may be needed to better estimate the range of sediment concentration magnitudes and durations, and the potential changes to these over a series of operations and storm events, because it is possible that suspended sediment concentrations could be much higher.

As a comparison, the published sediment data for the Condit and Marmot dam removal projects were also reviewed. Condit Reservoir contained approximately 510 AF of silt and clay sediments (Wilcox et al. 2014), a quantity similar to that found at LPR, but Marmot Reservoir was said to contain zero silt and clay sediment (Major et al. 2012). Drawdown and flushing of Condit Reservoir through a tunnel produced sediment concentrations up to 850,000 mg/L to the White Salmon River downstream, consisting of silt, clay, and sand. Total sediment concentrations above 2,000 mg/L lasted about 4 weeks following dam breaching (Wilcox et al. 2014). Drawdown and flushing of Marmot Reservoir through an uncontrolled cofferdam breach produced a peak suspended sediment concentration of 49,000 mg/L initially to the Sandy River downstream, consisting primarily of silts and clays and transitioning primarily to sand within an hour. Suspended sediment concentrations were probably similar to those upstream of the reservoir within 2 months of dam breaching; at 7 months after breaching, this was confirmed to be the case (Major et al. 2012). Fish response to suspended sediment was not monitored in the White Salmon or Sandy Rivers.

Studies of the Carmel River's response to the removal of San Clemente Dam (Harrison et al. 2018) found that prior to dam removal, turbidity in the river downstream of the dam increased to about 400 formazin nephelometric units (FNU) in response to modest flows of less than a 2-year return interval. For the water year during and immediately following dam removal, turbidity increased beyond the range of the instrument (above 1,600 FNU) during two events of similar size; in the second water year following dam removal, a series of flood events caused a hysteresis effect on turbidity over the duration of each event. Turbidity concentrations were higher during the rising limb of the hydrograph than during the falling limb, suggesting a lack of sediment delivery from the upper watershed during the later stages of the floods. Concentrations overall were lower during the last and largest event than during the preceding events of that second water year, also suggesting a generally sediment-supply-limited watershed. Harrison et al. (2018) posit that supply is limited due to the presence of LPD, which continues to trap sediment. These findings contrast with the results of a study that evaluated the relationship between flow and suspended sediment concentrations over some of the same 2017 storms, but on the San Lorenzo River. East et al (2018) found that suspended sediment concentrations were generally higher on the falling limb of the storm hydrographs. Together, these studies suggest that, during storms, steelhead in the Carmel River downstream of LPD are currently exposed to suspended sediment concentrations that are lower than would naturally occur in the absence of LPD and LPR.

To conclude, the 1,300 mg/L peak concentration resulting from the episodic rating curve represents a typical high-turbidity event contributing to the reservoir from the watershed as background conditions. The 5,800 mg/L peak concentration resulting from the hypothetical discharge of all Zone 1 sediment represents a sediment release condition where a portion of the reservoir sediment leaves the reservoir in flows that are consistently high over several consecutive days. Based on literature review of previous dam removal projects that included sediment flushing, a true flushing event can put orders of magnitude more material in suspension than the estimates above, potentially resulting in peak concentrations of 49,000 mg/L and greater. The reviewed dam removal data showed high suspended sediment concentrations lasting for 1 to 2 months, but those conditions occurred because of continuous access to reservoir sediments afforded by long periods of high flow in the White Salmon and Sandy Rivers, which do not tend to occur on the Carmel River. The duration of high sediment concentrations would be limited by the operation of the sluice gate at Los Padres, which would typically restrict high sediment concentration durations to 2 to 5 days.

Based on the general predictions of suspended sediment concentration and durations, the results of Newcombe and Jensen (1996) were used to assess impacts of suspended sediment on steelhead. Newcombe and Jensen (1996) reviewed and synthesized 80 published reports of fish responses to suspended sediment in streams and estuaries, and established a set of equations to calculate severity of ill effect (SEV) indices (Table 3) for various species and life stages, based on the duration of exposure and concentration of suspended sediment present. The SEV provides a ranking of the effects of suspended

Table 3 Scale of the Severity of Ill Effects Associated with Suspended Sediment

Category of Effect	Severity	Description
Nil effect	0	No behavioral effects
Behavioral effects	1	Alarm reaction
	2	Abandonment of cover
	3	Avoidance response
Sublethal effects	4	Short-term reduction in feeding rates Short-term reduction in feeding success
	5	Minor physiological stress: • Increase in rate of coughing • Increased respiration rate
	6	Moderate physiological stress
	7	Moderate habitat degradation Impaired homing
	8	Indications of major physiological stress: • Long-term reduction in feeding rate • Long-term reduction in feeding success • Poor condition
Lethal and paralethal effects	9	Reduced growth rate: • Delayed hatching • Reduced fish density
	10	Increased predation of affected fish; 0 to 20% mortality
	11	>20 to 40% mortality
	12	>40 to 60% mortality
	13	>60 to 80% mortality
	14	>80 to 100% mortality

Source: based on Newcombe and Jensen 1996 sediment concentrations on salmonid species, as calculated by any of six equations that address various taxonomic groups of fishes, life stages of species within those groups, and particle sizes of suspended sediments. Newcombe and Jensen (1996) collected data on fish effects (on the SEV scale), suspended-sediment concentration (C, mg/L), and suspended-sediment exposure time (D, hr.) from a large number of papers dealing with many salmonid fishes at various life stages. The result of this approach is a life-stage-specific prediction of the SEVs on steelhead in Carmel River, based on the general predictions of suspended sediment concentrations and durations described above for sediment sluicing.

Because many of the studies included in Newcombe and Jensen’s (1996) analysis are laboratory studies, the results they describe may be a conservative estimate of the effects that may be experienced by steelhead exposed to elevated concentrations of fine sediment in the Carmel River. Under laboratory conditions, a fish would have no refuge from elevated suspended sediment concentrations. However, in a stream, fish may reduce their exposure to suspended sediment by seeking refuge in the mouths of tributaries with lower levels of suspended sediment, or where springs or other features provide inputs of water to the river and locally reduce suspended sediment concentrations. It is likely that steelhead in the wild would take advantage of these types of local variations in suspended sediment concentrations and, during extreme events, reduce their felt SEV from that predicted by the equations derived primarily from laboratory study. In this TM, the effects of suspended sediment are described based strictly on the equations provided by Newcombe and Jensen (1996) and should be considered a conservative assessment of potential effects in that regard. This approach is useful for a general assessment of sediment released under a sluicing alternative, but a more site-specific and nuanced analysis may be appropriate when evaluating the potential effects of a selected alternative or sediment management option on steelhead in the Carmel River.

2.3 Water Availability

Nearly all elements of juvenile steelhead rearing habitat are strongly influenced by instream flows, which affect rearing habitat area, the depth and volume of pools, connectivity between habitat types, water velocity, and water temperatures. Streamflow also dictates the quantity of drifting invertebrates that reach feeding steelhead (Harvey et al. 2006); higher summer flows allow steelhead to better maintain feeding rates during periods of higher water temperatures, when metabolic demands are greater (Krug et al. 2012). Ohms et al. (2021) used a nonlinear regression fit to a stock-recruitment model to estimate the relative steelhead production in the Carmel River, based on juvenile steelhead density, environmental variables, and the number of adult spawning fish. This allowed various comparisons to be made of flow metrics and their effect on relative steelhead production, including 1) between spring flow (March through May) and summer flow (July through September); and 2) between a general measure of flow prior to infiltration into the aquifer and “local” flow as represented by flow measured in the canyon (Sleepy Hollow gauge), upper valley (Don Juan gauge), and lower valley (Near Carmel gauge). In general, variation in summer flow was a better predictor of juvenile production than variation in spring flow; and variation in local flow was a better predictor of juvenile production than pre-infiltration flow, as represented by the Robles del Rio gauge. The results of Ohms et al. (2021) suggest that flow during the summer rearing life stage is more of a limiting factor for steelhead than flow during egg incubation and the early fry life stages. In addition, the results suggest that infiltration into the aquifer is an important influence on steelhead productivity, above and beyond the effects of water releases from LPR, as evidenced by the lower river routinely drying out while releases are being made from LPR.

In central California watersheds, the most geographically restricted habitat type is probably summering habitat, due to the Mediterranean climate and the general aridity of the region (Boughton and Goslin 2006). In their assessment of suitable steelhead habitat, NMFS researchers Boughton and Goslin (2006) state that steelhead over-summering habitat is thought to have a restricted distribution, more so than winter spawning and rearing habitat. Citing Spina et al. (2005), Boughton and Goslin (2006) further conclude that low summertime flows are probably an important limiting factor for steelhead in arid California watersheds, given the prevalence of intermittent streams in the region. Furthermore, the habitat requirements and critical environmental factors for different age classes of juvenile steelhead are relatively similar, but as fish grow, they require more space for foraging and cover. Because of their larger size, older juvenile steelhead (age 1+/2+) have higher energetic demands; they require deeper, more complex pools, and large rocky substrate or in-channel wood for cover while feeding (Hartman 1965; Fontaine 1988; Spina 2003). Rivers can typically support far fewer older and larger age 1+ trout than age

0+ trout. This results in a large mortality in fish during their first year of life, as they grow and encounter habitat limitations that constrain the number of larger and older fish that can be supported (Elliott and Hurley 1998). Therefore, flow requirements for age 1+ juveniles are considered to be especially critical for steelhead in the Carmel River watershed.

Currently, water availability in the Carmel River downstream of LPD during the dry season is controlled by seasonal hydrology and water release operations at LPD. As described in Section 2.4 in the context of water release temperature, the ability to provide reservoir releases at specific rates and locations has been affected by episodic landslides, including a series of landslides that has limited use of the low-level outlet over the past several years. Recent research suggests that future interannual sediment yield variations will become more extreme, and episodes of sediment deposition will become more frequent (East et al. 2018). Although California American Water (Cal-Am) is planning a new low-level outlet that would improve reliability (see Section 2.4), water available for maintaining steelhead summer and fall rearing habitat downstream of LPD will continue to depend on mechanical infrastructure if LPD is in place, and could be subject to unpredictable operational issues affecting reservoir releases. The following subsections describe how hydrologic and hydraulic models are used to compare water availability and its effects on steelhead across alternatives in this TM.

2.3.1 Watershed Hydrology

The CRBHM (Christensen et al. 2021) was developed to evaluate hydrologic effects related to changes in water supply, groundwater pumping, and climate change in the Carmel River watershed. Considerable time was spent by MPWMD and their collaborators reviewing and calibrating the CRBHM in coordination with the TRC, some of which is captured in meeting summary presentations prepared by MPWMD (Attachment A). Nash-Sutcliffe Efficiency (NSE) values were used to evaluate the ability of the CRBHM to predict actual streamflows. From these presentations, we know that NSE values of 0.65 and greater are considered acceptable and that NSE values calculated for the CRBHM ranged between 0.72 and 0.78 for each model node, on a daily timestep, during the low-flow period of April through October. MPWMD described how the CRBHM often shows streamflows in response to the first rains of each water year that are not actually observed in the Carmel River, and how efforts to eliminate this artifact from the model created other issues. The root mean square error (an indication of how concentrated the data are around the line of best fit) of the calibrated model for daily low flow (May through September) under 50 cfs for different stream gages ranges from 8.5 cfs to 11.9 cfs.

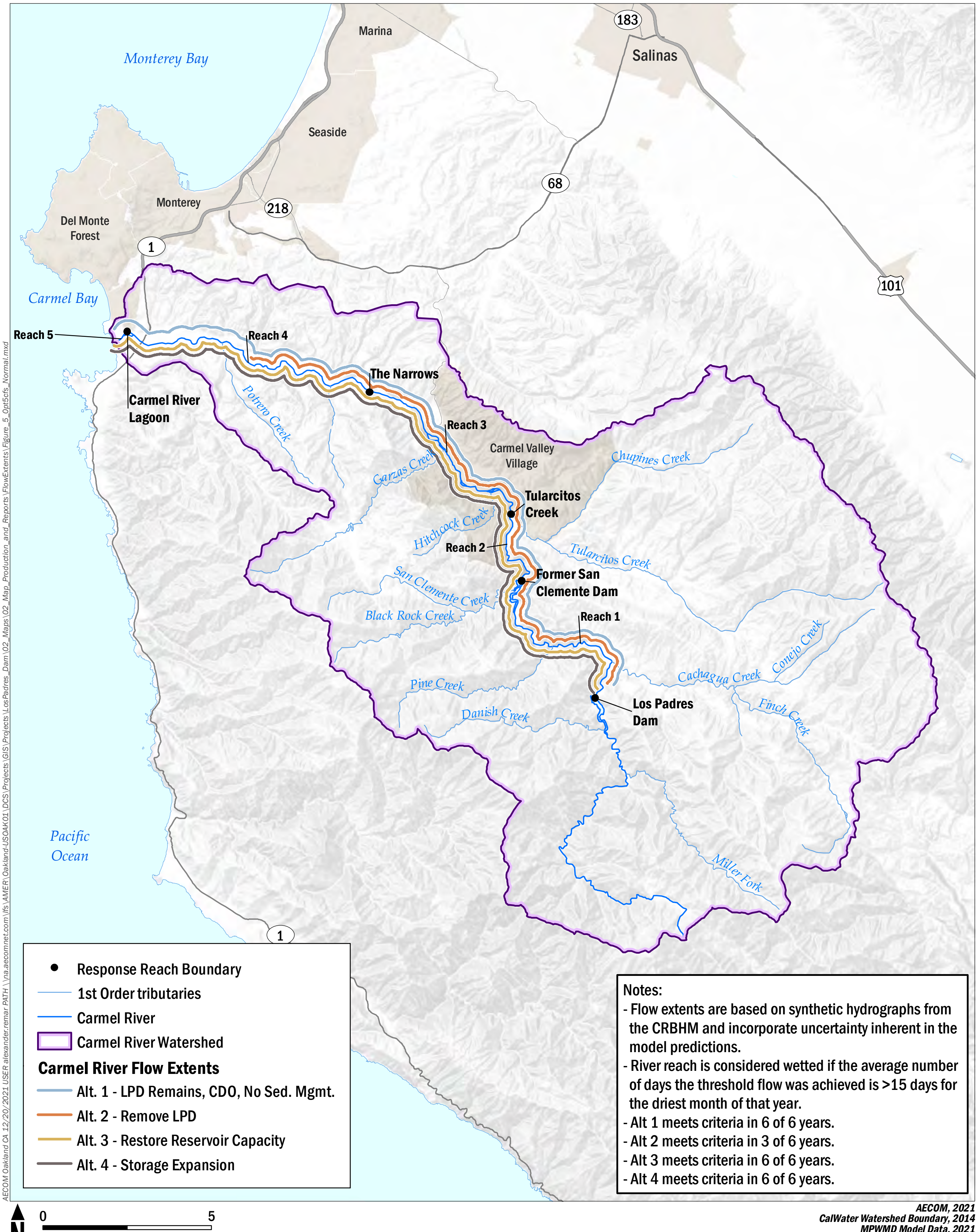
In this TM, the water availability analyses focus on low flows from July through September. MPWMD has pointed out that in many years the modeled spring recession is a good predictor of observed flows, and the model shows seasonal drying in many areas where drying is observed in the lower Carmel River. MPWMD also noted that where model predictions of spring recession deviated from observed values, the predicted flow was higher than observed in some years and lower in others; calibration efforts sought to balance these deviations. Currently, D. Boughton (Boughton, pers. comm., 2021) is working on a comparison of the outputs of the CRBHM with measured gauge data showing that infiltration in the lower Carmel River is consistently underestimated by the model. Although there is uncertainty in the absolute, instantaneous flow rates predicted by the CRBHM, relative differences are emphasized in this TM when comparing the effects of the alternatives on water availability. Notably, MPWMD has stated that if the CRBHM overpredicts flow rates during a given year, that same deviation is seen across all model scenarios—in which case, the relative comparison is still useful for perceiving differences among alternatives.

The following CRBHM scenarios, including any uncertainty or inaccuracy associated with the model predictions, were used to assess the potential effects of the dam and reservoir alternatives on steelhead:

- **LPD Remains, Cease and Desist Order, No Sediment Management:** This model is configured to represent cease and desist order (CDO) pumping (3,376 acre-feet per year [AFY]) and aquifer storage and recovery (ASR) diversions, with the LPR in place with its current storage and operation. MPWMD determined that the most likely CDO-compliant pumping of 3,376 AFY would be carried out by pumping 600 AF from June through November (100 AF per month). The remaining 2,776 AF would be pumped out from December through May (462.7 AF per month). It was understood that summer pumping would be minimized to help steelhead in the lower river, but 100 AF of pumping per month was required to keep the Begonia Iron Treatment Removal Plant operating. All pumping would occur in lower Carmel Valley at Cal-Am's Cañada, Cypress, and Pearce wells, in accordance with the existing State Board Order that requires pumping in the lower valley instead of wells higher in the system. This applies to **Alternative 1**.

- **Remove LPD:** This model is configured to simulate removal of LPD, with a water right of 3,376 AFY, which reflects the CDO pumping. All pumping remains in lower Carmel Valley at Cal-Am's Cañada, Cypress, and Pearce wells, in accordance with the existing State Board Order that requires pumping in the lower valley instead of wells higher in the system. In addition to pumping that complies with the CDO, ASR diversions are accounted for. This applies to **Alternative 2**.
- **Restore Reservoir Capacity:** This model is configured to simulate a dredged LPR (excluding the rubber dam), with a water right of 3,906 AFY, which reflects the dredged LPR capacity (2,709 AF) and pre-1914 and riparian rights (1,197 AF). This assumes that a new water right would allow additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit. The model scenario assumes that diversions remain in lower Carmel Valley at Cal-Am's Cañada, Cypress, and Pearce wells. Summer pumping is fixed at 100 AF per month, and the new winter pumping was set at 3,306 AF (3,906 - 600 = 3,306). This equates to 551 AF per month (December through May). This applies to **Alternative 3**.
- **Storage Expansion (Rubber Dam):** This model is configured to simulate installation of a rubber dam and dredging of LPR, with a water right of 4,492 AFY, which reflects additional storage capacity at LPR (3,295 AF) and pre-1914 and riparian rights (1,197 AF). This assumes that a new water right would allow additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit. The model scenario assumes that diversions remain in lower Carmel Valley at Cal-Am's Cañada, Cypress, and Pearce wells. Summer pumping is fixed at 100 AF per month, so the new winter pumping was set at 3,892 AF (4,492 - 600 = 3,892) or 648.7 AF per month, December through May. Water released from LPR would provide instream, environmental flows until it is picked up by the lower wells. This applies to **Alternative 4**.

The CRBHM was used to develop several sets of figures used in this TM to compare alternatives, each of which incorporates uncertainty inherent in the model predictions. The figures include flow exceedance curves (presented in Section 3.1.2) for the Carmel River at Highway 1, Garzas Creek Confluence, and downstream of LPD (Figure 1). These locations were selected to correspond with critical steelhead rearing areas discussed in the Study Prep TM (AECOM 2017a) and the instream flow incremental methodology (IFIM) Study (Normandeau 2019), as described in Section 2.3.2. Exceedance curves graphically display the probability that a flow of a given magnitude will be exceeded at a given location. Due to the limiting factors associated with low summertime flows, exceedance curves were generated to compare flow conditions among alternatives during the low-flow period (July through September). Exceedance curves were generated using CRBHM model years (1992 through 2015) for all water years. Additionally, exceedance curves were generated using average flow conditions during dry and critically dry years to compare alternatives during years when Carmel River steelhead would be most susceptible to the effects of each alternative. When applied to the dry season, the exceedance curves provide a relative comparison of the percentage of time that rearing flows are equaled or exceeded under each alternative. Data summarized from the CRBHM were also used to develop maps that display the predicted downstream extent to which critical flows extend in the Carmel River under the proposed alternatives during the dry season (July through September) of normal water years, including flows exceeding 0.5 cfs, 3 cfs, and 5 cfs (Figure 5 through Figure 7). The low-flow values were selected for comparison because they encompass the range of flows within which the extent of steelhead summer rearing habitat can be affected by small changes in flow. Due to the low flows presented in these figures, relative to the error inherent in the CRBHM, these figures should be used to compare and assess the relative effect of alternatives on downstream flow, rather than the absolute magnitude or absolute extent of flow under any given alternative.



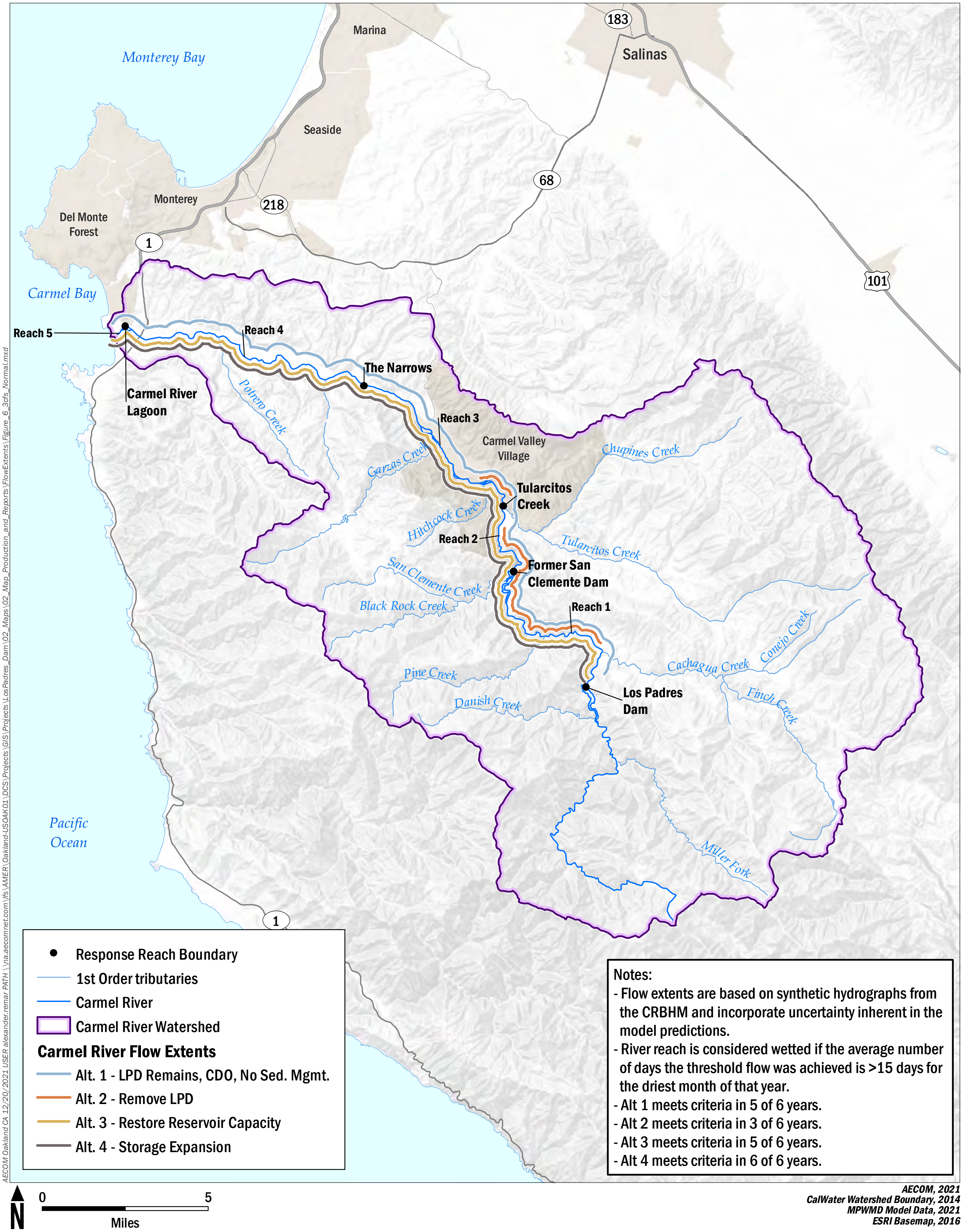
AECOM, 2021
CalWater Watershed Boundary, 2014
MPWMD Model Data, 2021
ESRI Basemap, 2016

AECOM

Monterey Peninsula Water Management District
Los Padres Alternatives Study

FIGURE 5

Extent of Carmel River Flows (0.5 cfs) in July through September under LPD Project Alternatives during Normal Years



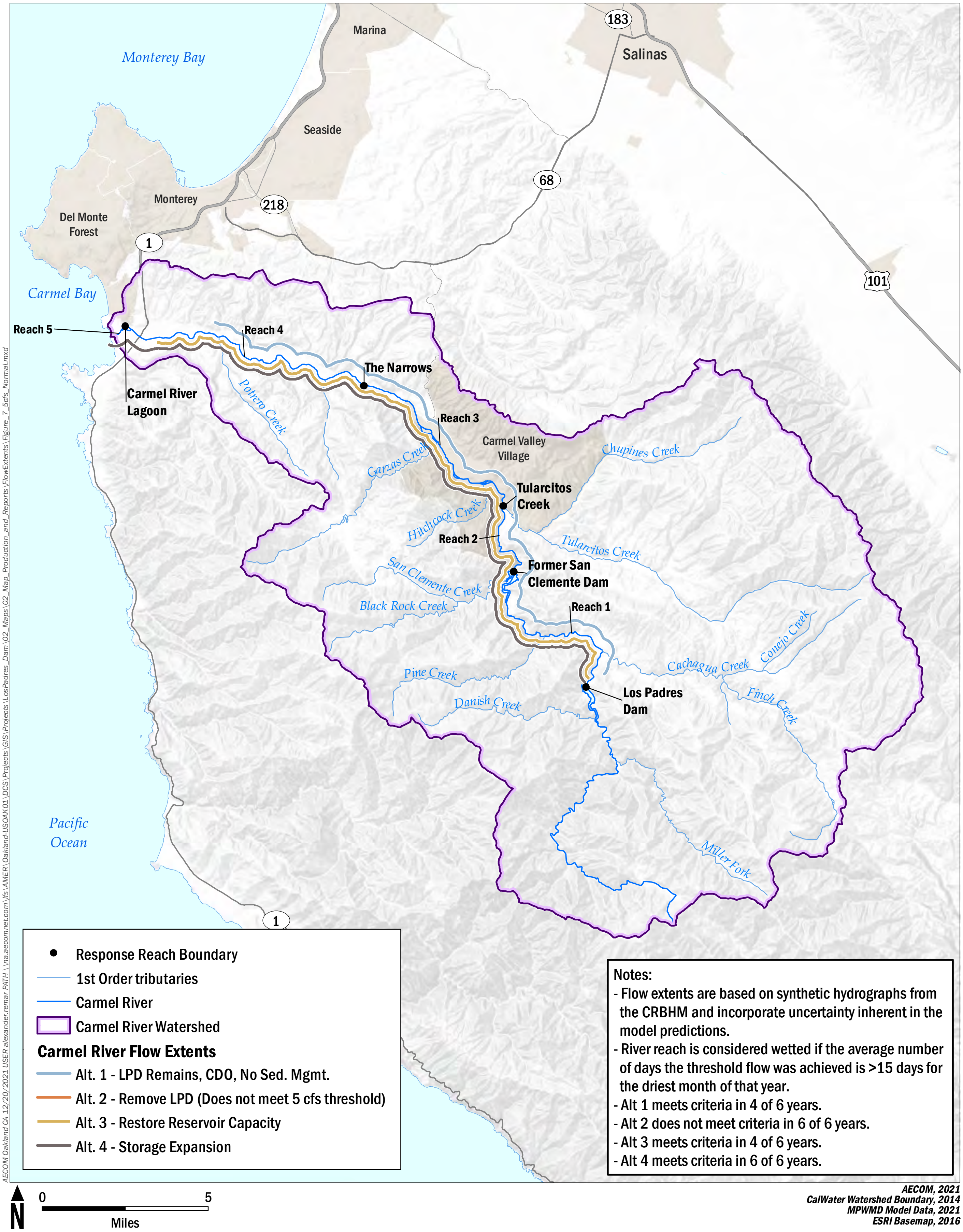
AECOM, 2021
CalWater Watershed Boundary, 2014
MPWMD Model Data, 2021
ESRI Basemap, 2016

AECOM

Monterey Peninsula Water Management District
Los Padres Alternatives Study

FIGURE 6

Extent of Carmel River Flows (3 cfs) in July through September under LPD Project Alternatives during Normal Years



AECOM, 2021
CalWater Watershed Boundary, 2014
MPWMD Model Data, 2021
ESRI Basemap, 2016

AECOM

Monterey Peninsula Water Management District
Los Padres Alternatives Study

FIGURE 7

Extent of Carmel River Flows (5 cfs) in July through September under LPD Project Alternatives during Normal Years

2.3.2 Steelhead Habitat in Relation to Instream Flow

Hydrologic conditions in the Carmel River watershed affect habitat conditions for steelhead, including migration, spawning, and rearing, and vary under each project alternative. An instream flow study for the Carmel River was prepared, using IFIM, by Normandeau (2019). The results of the IFIM were intended to support a variety of studies and efforts in connection with managing the Carmel River lagoon, evaluating options for the future of LPD, and evaluating operational changes due to proposed water supply projects that replace Carmel River diversions. Suitable steelhead habitat was mapped and modeled under a range of flows. NMFS (2018) provided extensive review of the IFIM report, and strongly stated that the IFIM results should not be used in isolation from other analysis to set instream flow targets in the Carmel River. NMFS was concerned with the accuracy of the results in recognition of changing channel morphology, use of habitat suitability criteria, and limiting factors for steelhead in the watershed. In this evaluation, the results of the IFIM were used to assess general patterns in rearing habitat availability for steelhead during the low-flow season under the alternatives considered, while recognizing the limitations and uncertainty of the IFIM approach.

The IFIM combined the hydraulic and habitat suitability criteria components to generate a habitat suitability index, often termed “weighted usable area”; in Normandeau (2019), the index is more accurately termed “area-weighted suitability.” Although the relationship between flow and habitat may be more complex than is captured in the IFIM, it is among several tools available for comparing alternatives. The IFIM study (Normandeau 2019) found that, for juveniles (> 6 centimeters [cm] FL), habitat generally increases with increasing flows. Flows between 25 and 75 cfs produced maximum or near-maximum habitat for juveniles upstream of the Narrows (Figure 1), and higher flows produced a greater amount of habitat downstream of the Narrows. These flows producing maximum habitat in the Carmel River are much higher than would occur during summer in an unmanaged or historical condition and are higher than flows typically produced during summer when releases from LPR are managed to benefit steelhead. Juvenile rearing habitat declines rapidly as flows drop below 10 cfs and is of low abundance when flows are 5 cfs or lower. For fry (< 6 cm FL), habitat generally decreases with increasing flows, with maximum available habitat at flows around 5 cfs upstream of the Narrows. Higher flows (50 cfs) produced more habitat in the lower reach, likely due to the width of the channel and lower gradient of the river in this reach. For fry, habitat declines rapidly at flows less than 3 cfs.

Each of the CRBHM scenarios described in Section 2.3.1 was run through the IFIM in a time series analysis to predict rearing habitat duration for fry and juvenile steelhead (Normandeau 2021). The habitat duration graphs generated from the IFIM model outputs are displayed in Figure 8 and Figure 9. Because these graphs are based on synthetic hydrographs generated from the CRBHM, they are subject to accuracy limitations noted for the CRBHM. Juvenile habitat duration is displayed from July through September (Figure 8). In the Carmel River, steelhead fry rearing occurs primarily between April and June, although some fry-sized fish have been observed as late as July in some years. To display the effects of low-flow season on fry rearing, habitat duration is shown from the month of July only (Figure 9).

2.4 Water Temperature

Water temperature has a controlling influence on habitat suitability for all steelhead freshwater life stages. In the most general sense, temperatures lower than 20 degrees Celsius (°C) (68 degrees Fahrenheit [°F]) are considered suitable for rearing steelhead (Hayes et al. 2008); higher temperatures also can support rearing, depending on food availability, dissolved oxygen levels, and other factors. For example, as pool temperatures increase above 22°C, juvenile *O. mykiss* may move into temperature-stratified pools to seek cooler waters (Nielsen et al. 1994), and in laboratory studies have been shown to tolerate temperatures as high as 29.6°C for short periods of time (Myrick and Cech 2001). Streams such as the Carmel River experience daily temperature fluctuations because stream water warms during the day and cools at night, a pattern that changes across seasons. As a result, *O. mykiss* do not respond to the average stream temperature, but instead acclimate to a temperature between the mean and daily maximum temperatures (Hokanson et al. 1977). Although the relationship between *O. mykiss* growth and temperature is complex, for the purposes of comparing alternatives, this analysis focuses on average temperatures at various locations in the Carmel River and the direction of anticipated change associated with each alternative.

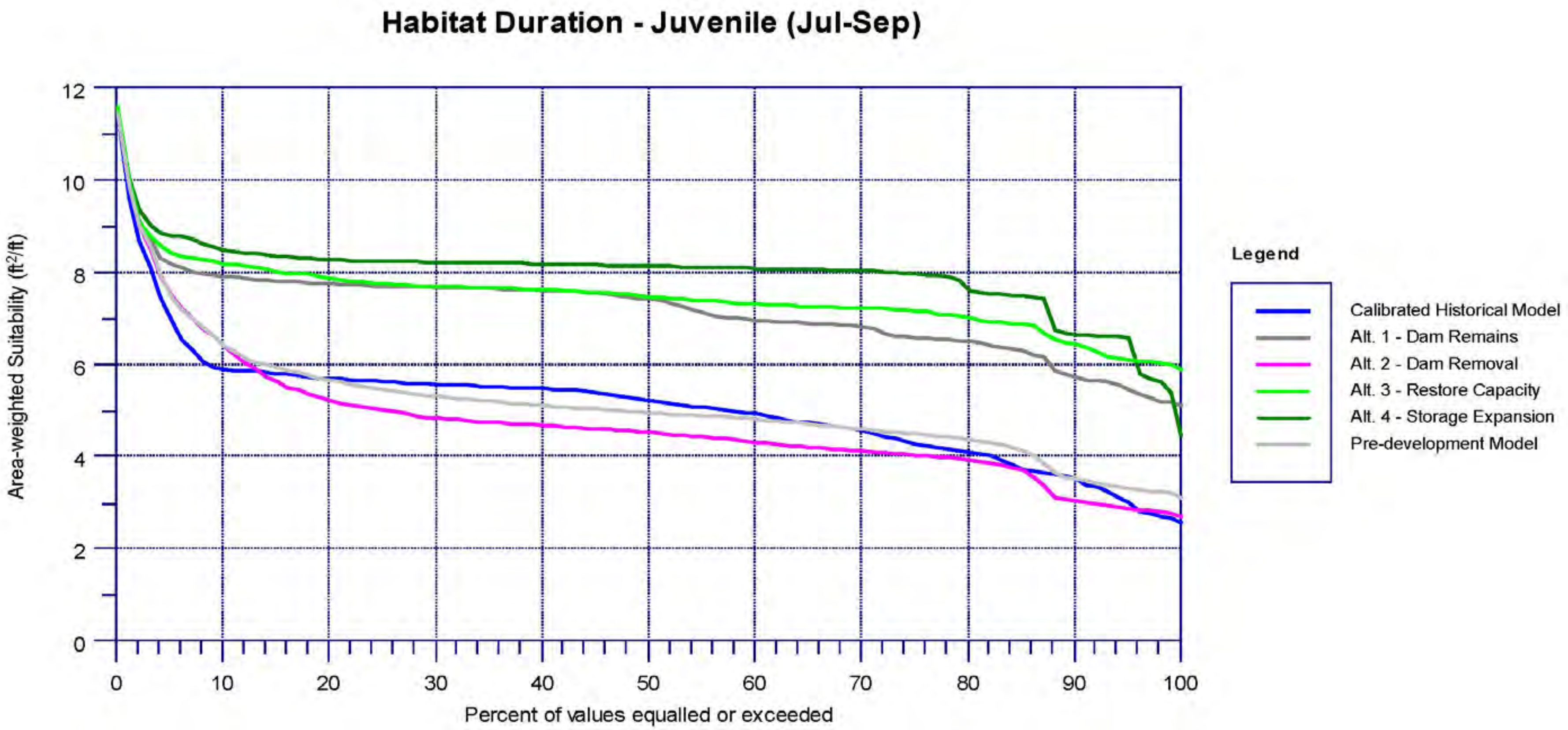


Figure 8 Habitat Duration Predicted by the IFIM Model for Juvenile Steelhead in the Carmel River (July–September), Based on CRBHM Predicted Flows

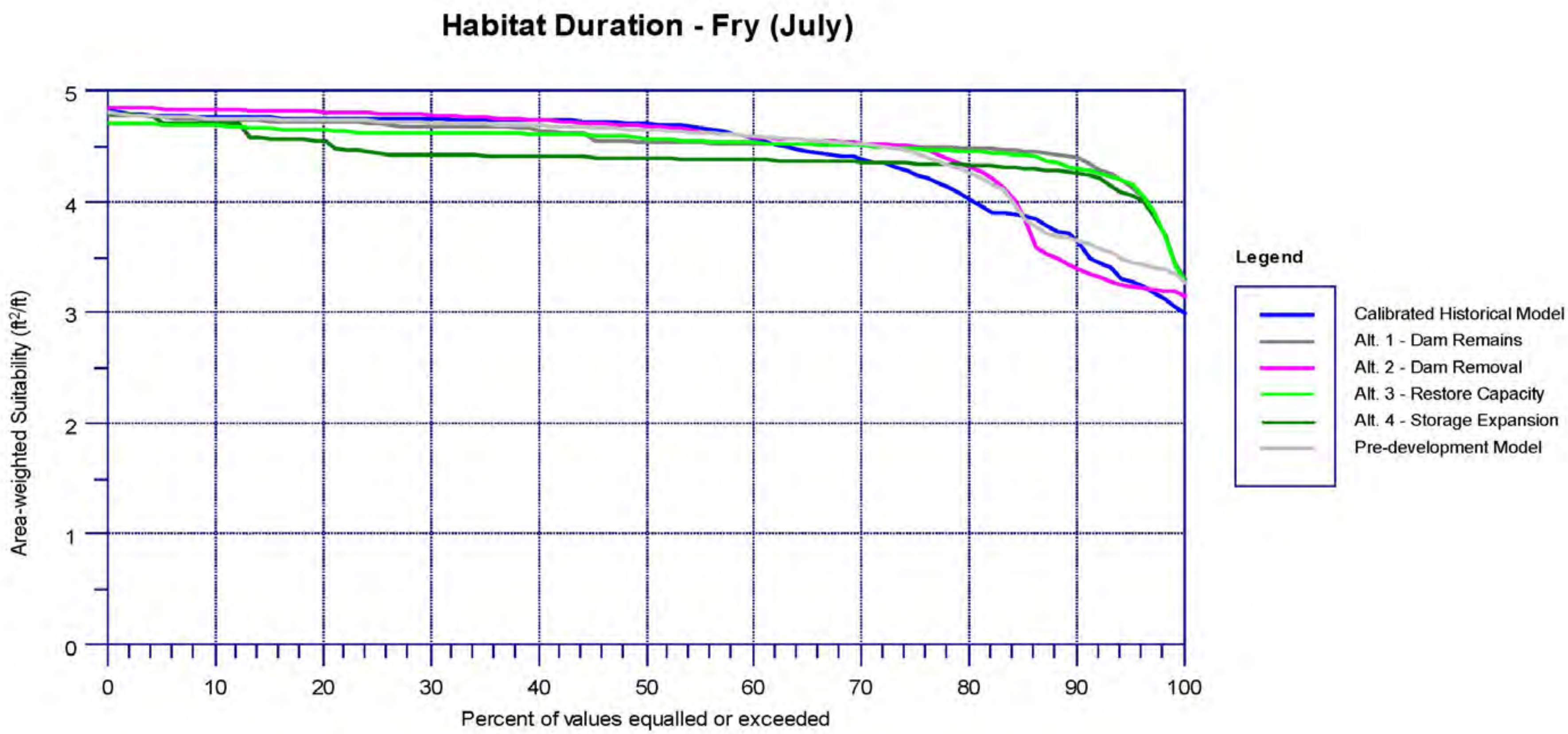


Figure 9 Habitat Duration Predicted by the IFIM Model for Fry Steelhead in the Carmel River (July), Based on CRBHM Predicted Flows

MPWMD and Cal-Am measure various water quality parameters at LPR. This includes water temperature, which has been recorded throughout the years at irregular intervals, with more frequent measurements taken in recent years (AECOM 2017a). Water temperatures in LPR appear to be stratified during spring and early summer, and generally mixed with no stratification in late summer and winter (AECOM 2017a). Downstream releases during times when the spillway is not flowing have typically occurred primarily from a low-level outlet at elevation 953 feet (North American Vertical Datum of 1988 [NAVD88]), and in recent years from a floating weir collector (FWC) at the reservoir's surface (until the water surface drops below elevation 1,036 feet [NAVD88], at which point the collector is rendered inoperable; see AECOM 2017a and HDR et al. 2021 for additional description of the dam's outlet works). There is also a high-level outlet at elevation 1,020 feet, 20 feet below the spillway crest, although it is rarely used. Currently, a temporary siphon is in use to convey water from the reservoir to downstream.

Due to recent landslides, the low-level outlet has become partially clogged and is only able to release a portion of the flows downstream (MPWMD 2019). Throughout the summer of 2021, the lower outlet has only been able to convey between 1 and 3 cfs downstream of the dam (HDR et al. 2021). To maintain downstream flow, a siphon and pertinent infrastructure were installed as a temporary water supply strategy to restore flow to the existing adult fish collection facility while the capacity of the low-level reservoir outlet is being restored. The siphon inlet is at elevation 1,002 feet, and a minimum 3 feet of water depth is required above the inlet screen. As the reservoir approaches elevation 1,005 feet (NAVD88), the flow reduces, so the lower limit of theoretical operation is at about elevation 1,010 or 1,011 feet (NAVD88). However, the siphon failed for unknown reasons in 2021, when the water surface elevation reached approximately 1,022 feet (NAVD88). The siphon can produce up to 19 cfs, but a throttling valve near the bottom of the siphon can reduce flows down to 2 cfs.

Because LPR is generally mixed by late summer, and based on the outlet release elevation, water released downstream of LPR is nearly always warmer than the water entering the reservoir from upstream (Figure 10). Although not shown in Figure 10, the reservoir also reduces the range of daily temperature fluctuations immediately below LPD. MPWMD intends to install a new low-level outlet in a location expected to be less impacted by landslides in summer 2022, and this analysis assumes that Alternatives 1, 3, and 4 include a new outlet at around elevation 974 feet, which is approximately 20 feet higher than the existing low-level outlet. Based on typical water surface elevations in late summer (August) of around 1,030 to 1,043 feet (AECOM 2017a), the outlet will be around 56 to 69 feet deep (17 to 21 meters). This depth of outlet will access the cold-water pool measured in LPR during spring and early summer, but is not anticipated to prevent warming of the water released from LPR to downstream reaches—especially in late summer and early fall, when the reservoir tends to be mixed and without a cold-water pool.

MPWMD conducts continuous water temperature monitoring at stations throughout the Carmel River (MPWMD 2017). Water temperature monitoring provides an indication of current temperature suitability for steelhead in the Carmel River. Water temperatures at the most upstream station (upstream of LPR near Danish Creek, Figure 1) are consistently the coolest of all the stations. During certain times of the year (e.g., September and October before removal of San Clemente Dam), water temperatures at the station below LPD are the highest of all the stations. In some months (e.g., April), water temperatures consistently warm as water moves downstream; in other months (e.g., September), water temperatures fluctuate as water moves downstream; and there may be a cooling effect as water moves downstream, depending on air temperature, riparian shading, and hyporheic exchange (AECOM 2017a). This cooling effect may have been reduced by the presence of the former San Clemente Dam, where water may have been subject to reservoir warming. Since removal of San Clemente Dam, summer water temperatures appear slightly cooler and winter temperatures appear slightly warmer; however, with less than 2 years of temperature data since the dam was removed, these differences cannot yet be attributed to dam removal, and a new pattern may emerge over time (AECOM 2017a).

Effects of each alternative on water temperature were evaluated conceptually based on the presumed influence of water temperatures in LPR to approximate the water temperatures under the alternatives.

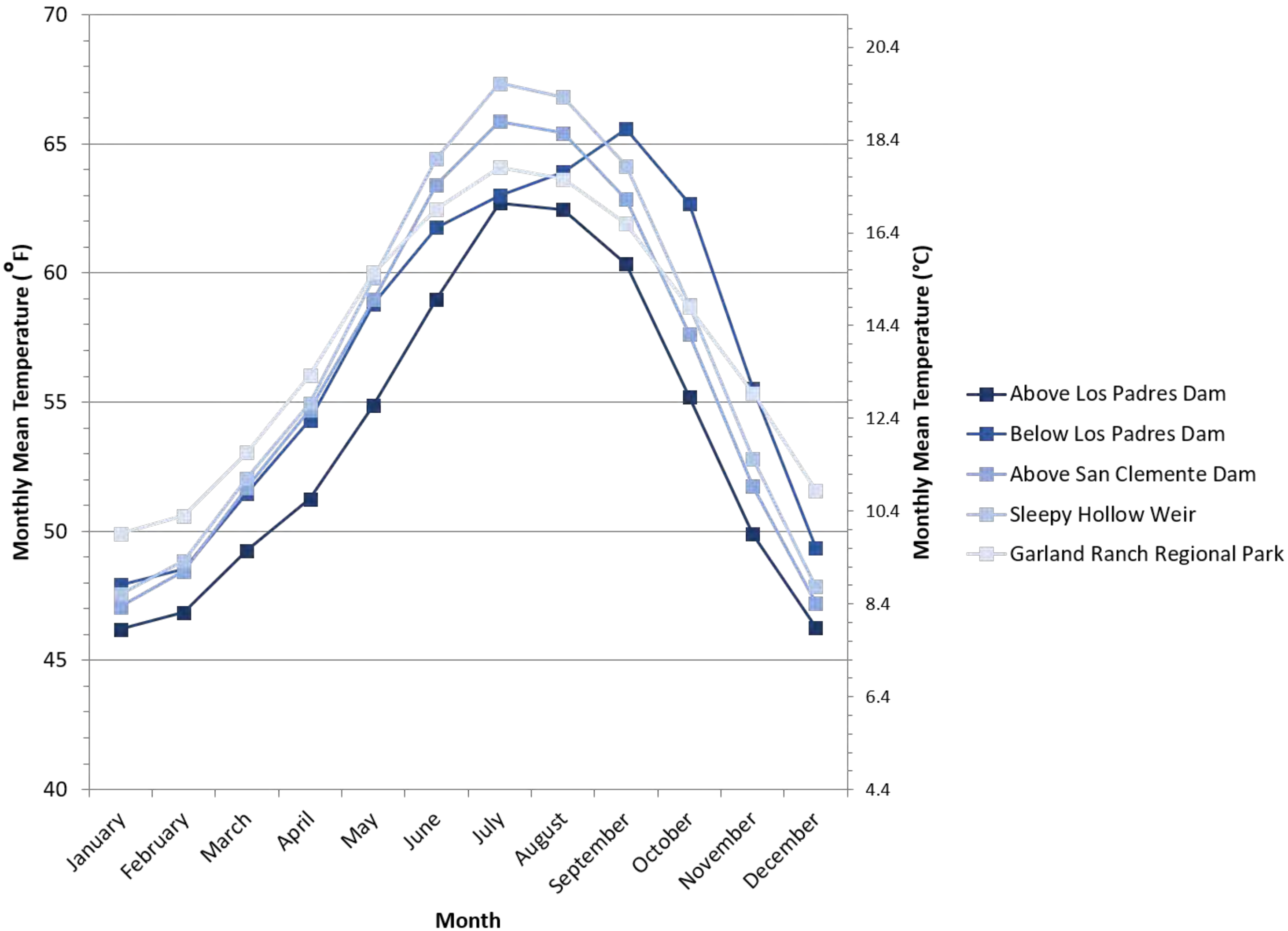


Figure 10 Average of Daily Carmel River Water Temperature for a Given Month before San Clemente Dam Removal (January 1996 through May 2014)

Source: MPWMD Unpublished Data

2.5 Fish Passage

LPD is a fish passage impediment for both upstream- and downstream-migrating steelhead in the Carmel River watershed. Under existing conditions, a Denil fish ladder is operated downstream of LPD, allowing adult upstream-migrating steelhead to ascend the ladder into a trap (HDR et al. 2021). Trapped steelhead are then transferred from the fish trap to a truck, transported upstream of LPD, and released into LPR. Current fish passage facilities for downstream-migrating steelhead consist of an FWC upstream of the LPD spillway, which guides downstream-migrating steelhead into a smolt bypass pipe that releases downstream of LPD. Nearly all downstream-migrating adults use the spillway to navigate LPD (Ohms et al. 2021); juvenile fish use both the spillway and smolt bypass system (HDR et al. 2021).

Ohms and Boughton (2021) conclude that, based on PIT tag monitoring to date, LPD and LPR are a significant downstream passage barrier for both juvenile and adult steelhead. Although improvements were made to the downstream passage facilities, Ohms and Boughton (2019) found that the majority of PIT-tagged juvenile downstream migrants were not detected at the smolt bypass. Of the 345 downstream migrants PIT-tagged moving from the upper watershed to the reservoir, 75 percent were estimated to have been "lost" in the reservoir, most likely due to mortality (e.g., predation) or remaining resident in the reservoir (Boughton et al. 2020). This estimate accounts for the probability of not being detected by the PIT tag antennae; that is, 25 percent is an estimate of the true number of fish that passed through the reservoir. Of the 25 percent that continued downstream, Boughton et al. (2020) estimated that most (2:1) went over the spillway but some used the behavioral guidance system (BGS) and FWC (see Figure 16 of Boughton et al. 2020).

Although the spillway seems to be used more frequently than the BGS for downstream passage, spillway passage is limited by low flows over the spillway and may be harmful to steelhead relative to passage via the BHG and FWC. Ohms and Boughton (2021) reported that juvenile outmigrants that used the FWC and BGS migrated downstream 36 hours faster than those that used the spillway, suggesting that the FWC was a less traumatic passage route that required less recovery time than spillway passage. Juvenile outmigrants stopped passing over the spillway when spillway-crest water depths dropped below 4.9 cm, and kelts stopped passing over the spillway when spillway-crest water depths dropped below 8.5 cm. Because of the limitations to spillway passage at low flows, Ohms and Boughton (2021) estimate that outmigrant spillway passage was severely to moderately limited in 40 to 55 percent of the last 20 years (2002–2021), and therefore most years do not have sufficient spring flows for downstream passage over the full migration season. It appears that retention of LPR under any of the alternatives is likely to result in a substantial proportion of downstream migrants failing to migrate through the reservoir, either due to predation or to using the reservoir to pursue an adfluvial life-history.

Flow depth and duration over the spillway are also important for downstream adult passage, and water year 2019 was characterized as extremely wet (Ohms and Boughton 2021). In 2019, 83 adult steelhead were captured in the fish trap at LPD, tagged, and released upstream of LPD into LPR. Boughton et al. (2020) found that nearly all (98.8 percent) the adult steelhead released into LPR were subsequently detected upstream of the reservoir, likely continuing upstream to spawn. After spawning, the majority (71 percent) of tagged adult steelhead kelts successfully passed through the reservoir via the spillway and were detected downstream of LPD. Nighty-eight percent of downstream migrating kelts used the spillway for passage, and 2 percent used the FWC (Ohms and Boughton 2021). One tagged adult steelhead was detected using the BGS. Another three of the 83 adult steelhead tagged were detected at the entrance of the BGS and subsequently detected again above the reservoir, indicating that the BGS might inhibit downstream movement of some adults (Boughton et al. 2020).

To improve steelhead populations in the Carmel River, Cal-Am entered into a Memorandum of Agreement with NMFS and the California State Coastal Conservancy to improve fish passage conditions at LPD (HDR et al. 2021). As part of identifying feasible fish passage facilities at LPD, The Fish Passage Feasibility Report (HDR et al. 2021) evaluated fish passage alternatives to inform management decisions regarding the future operations of LPD. HDR et al. (2021) identified two upstream passage alternatives at LPD for further consideration: Alternative U1 (technical fish ladder) and Alternative U8 (trap and transport – replace). The report also identified two downstream passage alternatives at LPD for further consideration: Alternative D1 (floating surface collector [FSC] – new) and Alternative D8 (spillway modification and FWC with 30 cfs attraction flow). These fish passage alternatives will be selected and adapted based on the selection of one of, or a combination of, the dam and reservoir alternatives and sediment management options evaluated in this report.

The fish passage alternatives were incorporated into this analysis by evaluating effects of fish passage conditions, focusing on the differences between managed fish passage for Alternatives 1, 3, and 4, and dam removal. Alternative 2 assumes dam removal, with volitional fish passage.

2.6 Summary

Several sources of information were available to evaluate the alternatives and options being considered at LPD, as summarized in Table 4.

Table 4 Summary of Information Available to Evaluate Alternatives and Options

Alternative/Option (AECOM 2017b)	Sediment Transport Scenario (BESMo) (Balance Hydrologics and UBC Geography 2019)	Basin Model Scenario (CRBHM) (Christensen et al. 2021)	IFIM Time Series Scenario (Normandeau 2019)	Fish Passage Scenario
Alternative 1: LPD Remains, CDO, No Sediment Management No action is taken to manage existing or future sediment in the reservoir	**No Action Simulation** No action is taken at LPD or LPR. Coarse sediment continues to accumulate in reservoir. Only bedload supply is from tributaries.	**Current Los Padres** Model configured to represent CDO pumping (3,376 AFY) and ASR diversions, with the LPR in place with its current storage and operation.	**Current Los Padres (CDO and ASR)** Incorporates CRBHM model for Alternative 1.	**U1: Technical Fish Ladder – Adult** **or** **U8: Trap and Transport – Replace** **and** **D1: Floating Surface Collector** **or** **D8: Spillway Modification (D5) and Existing FWC with 30 cfs Attraction Flow (D7)**
Alternative 2: Dam Removal Full (2a) or partial (2b) dam removal down to original riverbed; includes removal of Zone 1 and 2 sediment via sluicing or dredging	**Uncontrolled Supply Simulation** Assumes dam removal and release of all sediment deposits. Includes upstream watershed sediment supply.	**Remove LPD** Model configured to simulate removal of LPD, with a water right of 3,376 AFY, which reflects the CDO pumping. In addition to pumping that complies with the CDO, ASR diversions are accounted for.	**Remove LPD** Incorporates CRBHM model for Alternative 2.	**Volitional, no facilities**
Alternative 3 Restore Reservoir Capacity Sluicing or dredging and excavation of reservoir sediment to disposal sites	**No Action Simulation** No action is taken at LPD or LPR. Coarse sediment continues to accumulate in reservoir. Only bedload supply is from tributaries.	**Los Padres Expanded Storage** Model configured to simulate a dredged LPR (excluding the rubber dam), with a water right of 3,906 AFY, which reflects the dredged LPR capacity (2,709 acre-feet) and pre-1914 and riparian rights (1,197 acre-feet). This assumes that a new water right would allow additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit.	**Los Padres Expanded Storage - Dredging** Incorporates CRBHM model for Alternative 3.	**U1: Technical Fish Ladder – Adult** **or** **U8: Trap and Transport – Replace** **and** **D1: Floating Surface Collector** **or** **D8: Spillway Modification (D5) and Existing FWC with 30 cfs Attraction Flow (D7)**

Alternative/Option (AECOM 2017b)	Sediment Transport Scenario (BESMo) (Balance Hydrologics and UBC Geography 2019)	Basin Model Scenario (CRBHM) (Christensen et al. 2021)	IFIM Time Series Scenario (Normandeau 2019)	Fish Passage Scenario
Alternative 4: Storage Expansion Rubber dam in spillway for late season operation to increase storage for summer months (4b)	**No Action Simulation** No action is taken at LPD or LPR. Coarse sediment continues to accumulate in reservoir. Only bedload supply is from tributaries.	**Los Padres Expanded Storage** Model configured to simulate installation of a rubber dam and dredging of LPR, with a water right of 4,492 AFY, which reflects additional storage capacity at LPR (3,295 acre-feet) and pre-1914 and riparian rights (1,197 acre-feet). This assumes that a new water right would allow additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit.	**Los Padres Expanded Storage - Rubber Dam** Incorporates CRBHM model for Alternative 4.	**U1: Technical Fish Ladder – Adult** **or** **U8: Trap and Transport – Replace** **and** **D1: Floating Surface Collector** **or** **D8: Spillway Modification (D5) and Existing FWC with 30 cfs Attraction Flow (D7)**
Sediment Management Option 1 Permanent Disposal Excavation of Zones 2 and 3 and disposal at Sites B and C	**No Action Simulation** No action is taken at LPD or LPR. Coarse sediment continues to accumulate in reservoir. Only bedload supply is from tributaries.	—	—	—
Sediment Management Option 2 Sediment Injection/ Temporary Disposal Excavation of Zone 3 and placement at Sites D and E for mobilization	**Pulsed Supply Simulation** Pulses of bedload from LPR deposits are introduced into the river. Assumes a sluice tunnel with 5,000 cfs capacity and a minimum sluice flow of 500 to 1,500 cfs.	—	—	—
Sediment Management Option 3 Sluicing Tunnel Tunnel through dam abutment to sluice reservoir sediment during storm events	**Pulsed Supply Simulation** Pulses of bedload from LPR deposits are introduced into the river. Assumes a sluice tunnel with 5,000 cfs capacity and a minimum sluice flow of 500 to 1,500 cfs.	—	—	—

Notes:

AFY = acre-feet per year
ASR= aquifer storage and recovery
BESMo = University of British Columbia's one-dimensional morphodynamic sediment transport model
CDO = cease and desist order
cfs = cubic feet per second
CRBHM = Carmel River Basin Hydrologic Model
FWC = floating weir collector
IFIM = instream flow incremental methodology
LPD = Los Padres Dam
LPR = Los Padres Reservoir

3. Evaluation of Alternatives/Options on Steelhead

Following the approach described in Chapter 2, this chapter presents an analysis of the effects of the alternatives and sediment management options on steelhead in the Carmel River.

3.1 Alternative 1 (Los Padres Dam Remains, No Sediment Management)

Alternative 1 is based on a scenario in which LPD remains in place as under current conditions; no action is taken to manage the existing sediment accumulation in the reservoir, or future sediment inputs. This alternative serves as the baseline for comparing alternatives and is described in detail in AECOM (2017b).

3.1.1 Bedload Sediment Transport

The operation of dams can negatively affect sediment transport processes and the geomorphology of the affected drainages (NMFS 2011). Under Alternative 1, LPD would continue to prevent the transport of coarse sediment downstream of LPD through the Carmel River. Under existing conditions, bed elevations in the Carmel River downstream of LPD are degrading. Downstream of LPD, there is significant armoring of the streambed and incision into floodplain deposits along the lower 16-mile alluvial portion of Carmel Valley as a result of sediment retention at both LPD and the former site of the San Clemente Dam. Channel incision can result in the lowering of the groundwater table, reduced floodplain access, and decreased channel complexity (Bednarek 2001). A lack of bedload supply from upstream of LPD will cause the further incision of the Carmel River downstream of LPD through the lack of upstream gravel recruitment.

The BESMo model (Balance Hydrologics and UBC Geography 2019) predicts that under Alternative 1, the disruption in sediment transport would affect all reaches in the Carmel River. Pronounced effects would occur in the upstream portion of Reach 1, between LPD and Cachagua Creek (Figure 1). The simulations show that the low relative sediment supply downstream of LPD drives further channel bed degradation downstream to roughly the old San Clemente Dam location. BESMo predicts that the most significant spatial gradients in channel response are likely due to constructed channel conditions in the San Clemente Project Reach. Strong profile adjustments at this location are likely due to the constructed conditions; the reservoir deposit area is a location of channel bed erosion, with deposition predicted to occur between the new San Clemente Creek confluence and the former San Clemente Dam site. The reach from the former San Clemente Dam site to Tularcitos Creek is projected to have a wide range in the magnitude and spatial extent of aggradation and is highly dependent on hydrologic conditions. A general aggradation response of up to 5 feet is predicted to occur from Garzas Creek to the Narrows, followed by little to no change in deposition downstream to roughly the confluence of Robison Canyon Creek (Figure 1). Downstream of Robinson Canyon Creek, there is a consistent aggradation response of 2 to 5 feet relative to initial bed condition.

Coarse sediment contributes to suitable spawning and rearing habitat for steelhead, so preventing coarse sediment from transporting downstream would continue to have a negative effect on steelhead spawning and rearing habitat downstream of LPD. Others studying sediment transport in the Carmel River have postulated that spawning gravel will continue to be a limiting factor for steelhead until LPD is removed (Smith et al. 2021). Overall, under Alternative 1, the channel bed surface from LPD to the Pacific Ocean would continue to coarsen, despite the reintroduction of bedload supply from the reach between the former San Clemente Dam and LPD. Steelhead spawning habitat suitability is strongly related to suitable spawning gravel (AECOM 2017a). To mitigate the lack of bedload supply resulting from LPD, MPWMD has occasionally placed suitable spawning gravel in the Carmel River downstream of LPD, including 1,500 tons in 2014, 1,000 tons in 2019, and another 1,000 tons in 2021. In subsequent redd surveys conducted in 2019, 121 steelhead redds were observed in the newly placed spawning gravel between Schulte Road Bridge and LPD (Figure 1). The large number of redds observed in the newly placed spawning gravel suggest that the lack of gravel transport has an effect on spawning habitat; when gravel augmentation does occur, steelhead readily spawn in the newly placed gravel.

Adequate winter habitat is critical to steelhead populations, providing refuge from winter high-flow events (Solazzi et al. 2000). Steelhead prefer low-velocity pool habitats with large rocky substrate or woody debris for cover (Fontaine 1988; Hartman 1965; Raleigh et al. 1984; Swales et al. 1986). Large woody debris—in combination with other features, such as vegetated overhanging banks and interstitial spaces between cobbles and boulders—provide protection from high water velocities that can cause hazardous downstream displacement to less suitable habitat (Hartman 1965; Everest 1969; Bustard and Narver 1975; Grette 1985). Steelhead show less propensity than other species (e.g., coho salmon) for using off-channel slack-water habitats in winter, and a greater propensity for using in-channel cover such as that provided by woody debris—and, especially for age 0+ fish, the spaces between cobbles and boulder streambed substrates (Meyer and Griffith 1997; Finstad et al. 2007; Donaldson 2011). Such substrates have the advantage of being fairly common and usually immobile at all but the highest flows in higher gradient reaches. However, in-channel wood recruitment from adjacent riparian areas and from the upper watershed is restricted in the Carmel River due to removal activities and LPD, which makes steelhead in the Carmel River more dependent on cobble and boulder substrate for velocity refugia.

As the channel continues to incise, bank erosion will continue, perpetuating a loss of channel complexity, including loss of instream refugia (meanders, pools, undercut banks, etc.), pool habitat, and suitable gravel substrate; and a continued loss of access to overbank habitat during winter high flows (NMFS 2011). Decreased connectivity of the channel to overbank habitat would continue to limit important steelhead winter rearing habitat and high-flow refugia during winter storm events. However, as the bed continues to coarsen to a cobble-boulder-dominated habitat, there will be an increase in cobble and boulder substrate, which can also provide refugia for juvenile steelhead during high winter flows (Huber et al. 2011).

3.1.2 Water Availability

Under Alternative 1, LPR would continue to be filled in with sediment, further reducing the storage capacity of the reservoir. During dry periods (normally from May through October), releases from LPR constitute most flow in the river downstream of LPD (Cal-AM and MPWMD 2016). The reduction in storage would incrementally reduce the ability to enhance summer rearing habitat for steelhead in the Carmel River downstream of LPD through flow releases. Based on the current reservoir storage, average releases of 3.2 to 4.1 cfs can be made through the 6 months between April 15 and October 15 (AECOM 2017b). Over 60 years, the reservoir storage would be reduced by an estimated 450 to 950 AF, thereby reducing average releases between April 15 and October 15 to an estimated 1.3 cfs to 2.2 cfs.

Under existing conditions, approximately 1.5 river miles (RMs) of habitat between Boronda Road and Robles del Rio Road, and up to 9 RMs of habitat downstream of the Narrows to the lagoon, are seasonally subjected to dewatering, depending on the magnitude of streamflow releases at LPD, seasonal air temperatures, and water demand (MPWMD 2018). MPWMD conducts annual fish rescues when these portions of the Carmel River and tributaries begin to dry back, beginning in the spring and extending into the summer. MPWMD has rescued an average of 14,598 steelhead in the Carmel River Basin each year since fish rescues began in 1989. Rescued steelhead are either released upstream of the Narrows or reared in captivity at the Sleepy Hollow Steelhead Rearing Facility. Under Alternative 1, fish rescues would continue in the Carmel Basin so long as portions of the Carmel River dry back.

In addition to being at risk of dry back, the lower reaches of the Carmel River apparently support the fastest observed growth of juvenile steelhead in the watershed; slower growth is observed in the tributaries and upper mainstem (Ohms and Boughton 2019; Arriaza et al. 2017). Ohms and Boughton (2019) found that juvenile steelhead in the Carmel River Watershed that are larger in their first year are more likely to become anadromous steelhead; smaller individuals are more likely to delay ocean migration for another year or become residents (Phillis et al. 2016; Satterthwaite et al. 2009; Hayes et al. 2008). Ohms and Boughton (2019) concluded that, therefore, supporting flows and suitable conditions, specifically in the lower Carmel River, are critical to maintaining anadromous steelhead production in the watershed.

The IFIM predicts that habitat suitability for fry is generally highest around 3 to 5 cfs, and for juveniles is generally around 30 to 40 cfs, although the flow at which habitat is predicted to be maximized varies with different locations in the Carmel River (Figure 11). However, flows that maximize habitat for juveniles would not be achieved under unimpaired conditions during the late summer dry period, consistent with central coast watersheds, as discussed in Section 2.3.1. For fry rearing, flows greater than 3 cfs are predicted to provide abundant rearing habitat (Figure 13), especially in Reaches 2 and 3. For juveniles, flows greater than 5 cfs are predicted to provide suitable habitat that would support survival through the late summer period, especially in pools with depths greater than 1.5 feet. Overall, Alternative 1 is predicted to provide durations of suitable habitat for fry and juvenile steelhead similar to those under Alternatives 3 and 4, while providing a substantially greater duration of suitable habitat than Alternative 2 (Figure 12 and Figure 13).

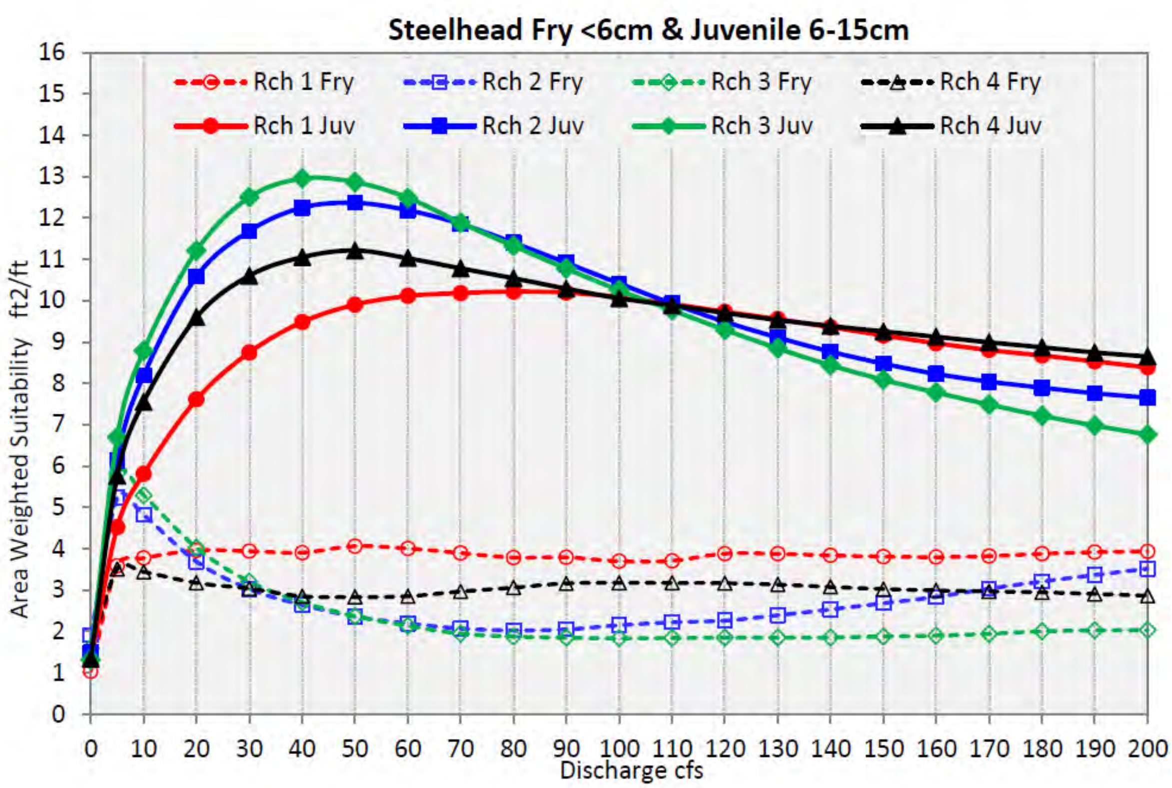


Figure 11 Area-Weighted Suitability Relationships for Fry and Juvenile Steelhead Rearing in the Carmel River

Source: Normandeau 2019

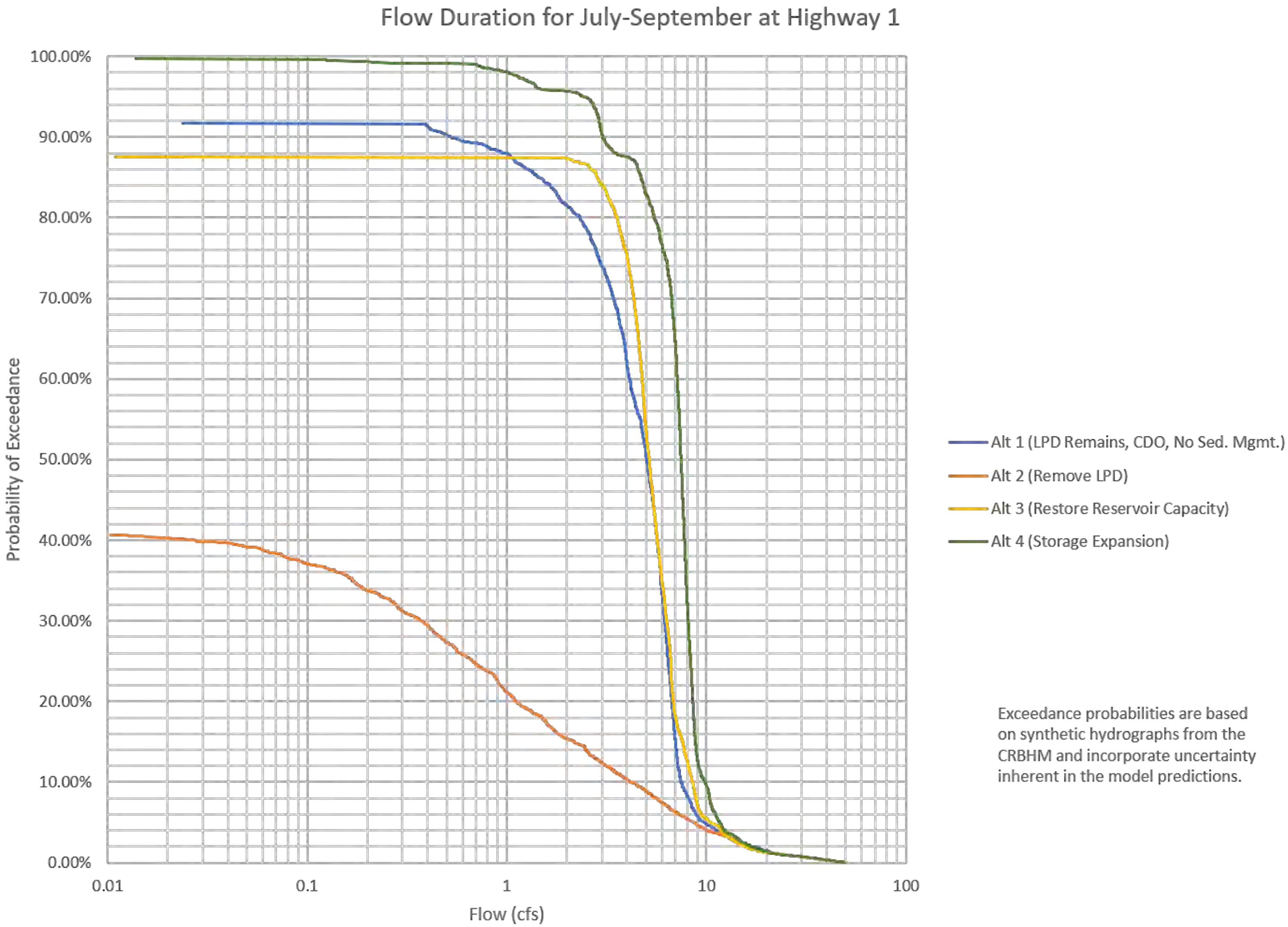


Figure 12 CRBHM Flow Exceedance Probability Curve for the Carmel River at Highway 1 for all Water Years during Low Summer Flow Conditions (July through September)

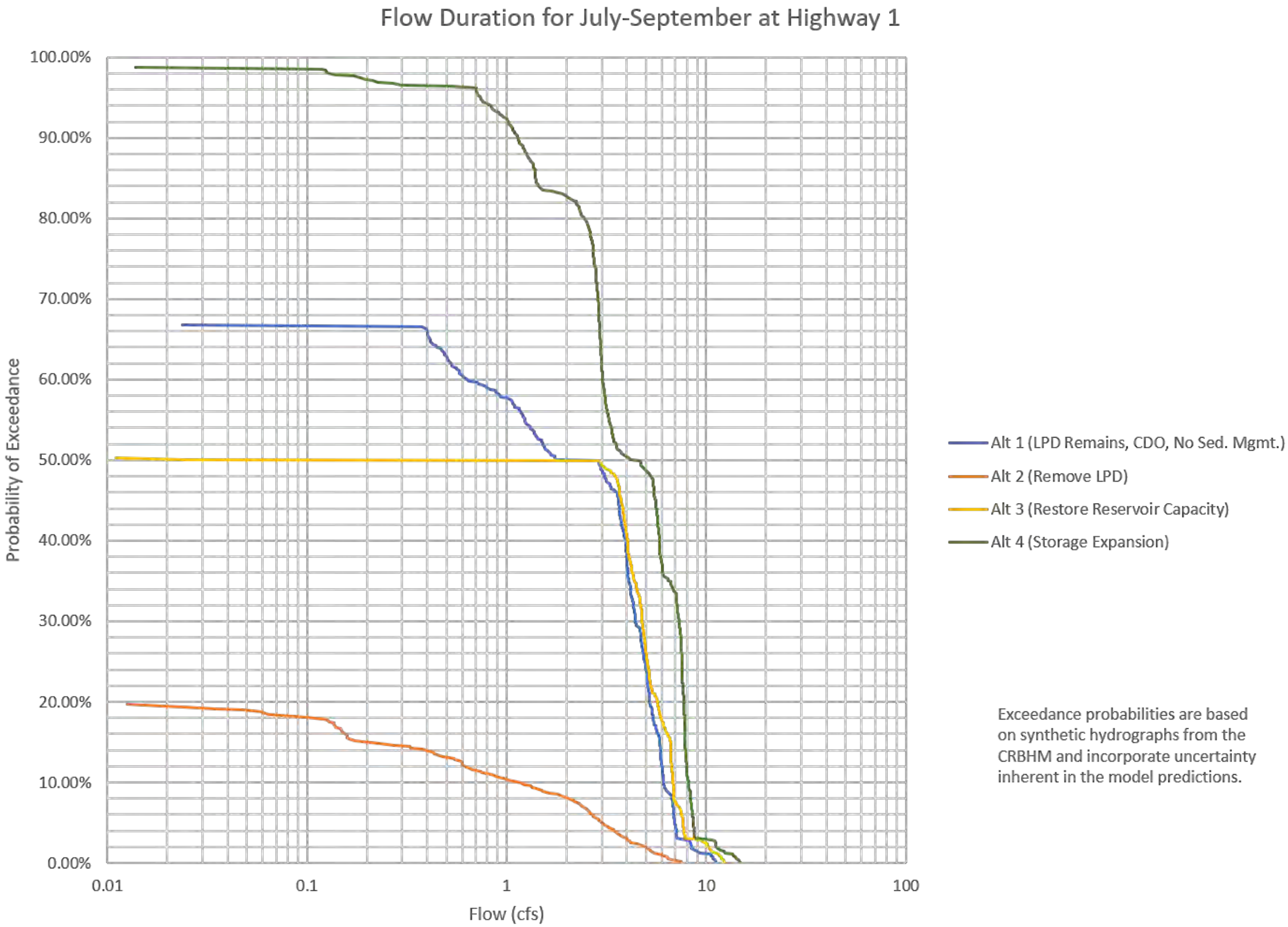


Figure 13 CRBHM Flow Exceedance Probability Curve for the Carmel River at Highway 1 for Dry and Critically Dry Water Years during Low Summer Flow Conditions (July through September)

Based on the CRBHM flow exceedance figures (Figure 12 and Figure 13), stream flows under Alternative 1 from July through September are predicted to be similar to those under existing conditions. During the summer, releases from LPD are predicted to provide flows for suitable fry rearing habitat (> 3 cfs) throughout most of the reach downstream of LPD—with the exception of the dry back that occurs in the lower Carmel River during some years (Figure 2). Based on the CRBHM model results, minimum flows to support juvenile rearing habitat (> 5 cfs) occur in the summer upstream of Reach 4 in most years (Figure 7). For example, at Highway 1 (Figure 12), 3 cfs is predicted to be exceeded 72 percent of the time during all water years and 50 percent during dry and critically dry years (Figure 13). Similarly, 5 cfs is predicted to be exceeded 50 percent of the time during all water years and 20 percent during dry and critically dry years (Figure 13) at Highway 1.

Based on the CRBHM flow extent figures (Figure 5 through Figure 7), under Alternative 1, the Carmel River is predicted to typically be wetted (> 0.5 cfs) from LPD downstream to the lagoon (around 25 RMs) in the summer months (July through September) of normal water years (Figure 5). Flows of 3 cfs in the Carmel River are predicted to generally occur in the summer months of normal water years downstream of LPD to the lagoon (Figure 6). Additionally, flows of 5 cfs are predicted to occur in approximately 21 miles of the Carmel River in normal water years under Alternative 1 (Figure 7).

Wetted habitat under Alternative 1 would provide benefits to rearing steelhead by providing more habitat and increased connectivity of the watershed in comparison to Alternative 2. Although estuarine habitats are generally productive juvenile steelhead rearing locations (Hayes et al. 2008), striped bass (*Morone saxatilis*) have been documented in the estuary, sometimes in high abundance, and are known predators of juvenile steelhead (Ohms et al. 2021). Currently, during periods when the Carmel River is connected to the estuary, striped bass have been observed as far upstream as Tularcitos Creek. Alternative 1 could potentially result in increases to the distribution of striped bass by maintaining a relatively wetted connection to the estuary. The relative benefits of additional juvenile rearing habitat, in contrast with the potential for increased mortality risk associated with an increase in striped bass distribution, has not been evaluated.

3.1.3 Water Temperature

Cal-Am intends to install a new low-level outlet in summer 2022; however, the general pattern of warming and reduced daily fluctuations in Reach 1 is anticipated to continue, as discussed in Section 2.4. In general, the effects of Los Padres Reservoir on water temperature are most pronounced in Reach 1 and the upper portion of Reach 2 and dissipate downstream as other influences dominate. Under existing conditions, water temperatures by Reach 3 (far enough downstream that the temperature influence of LPR is muted, and upstream of the most frequent summer dry back) appear to provide adequate rearing temperatures for steelhead during all water year types (MPWMD 2018, 2019, 2020, 2021).

Warm water temperatures may affect steelhead growth in some reaches even in wet years. Water years 2019 and 2020 were characterized as extremely wet and normal, respectively; however, temperature data from continuous data loggers indicated water temperatures at some locations that were within potentially stressful ranges for steelhead in the summer months (MPWMD 2019, 2021). These warmer temperatures were especially apparent in Reach 1 directly downstream of LPD and near the location of the former San Clemente Dam in Reach 2 (Figure 1), where stream temperatures reached the suboptimal range for steelhead during summer months (MPWMD 2019, 2021). These suboptimal water temperatures are known to reduce growth rates in juvenile steelhead (Harvey et al. 2006) and/or displace fish to other sections of the river with cooler temperatures (MPWMD 2020).

The exceptionally warm stream temperatures in the summer of 2020 were largely due to reliance on the LPD BGS for surface flows downstream of the dam and minimal use of the lower outlet, which had been clogged by landslides. This set of circumstances may have been unique, but the general pattern of water released from LPR being warmer than inflow is expected to continue, and unpredictable operational issues could continue to periodically amplify this effect.

With the continued presence of LPD under Alternative 1, juvenile steelhead subject to suboptimal water temperatures would not have the option to migrate upstream to thermal refugia in the cool water documented upstream of LPR. Instead, they would be forced to migrate downstream to seek cold water refugia (e.g., part of Reach 2, Reach 3, and Reach 4). Additionally, juvenile fish moving downstream as far as Reach 4 to avoid warmer water temperatures have the potential to become stranded when the lower Carmel River dries back during the late spring through fall. Increased metabolic demands associated with elevated water temperatures would continue to result in poor growth and low survival of any steelhead occupying areas with suboptimal water temperatures in the Carmel River during the low-flow period from summer through fall.

Warmer water temperatures also support and provide a competitive advantage for aquatic invasive species (e.g., largemouth bass [*Micropterus salmoides*], smallmouth bass [*Micropterus dolomieu*], and white bass [*Morone chrysops*]) (Rahel and Olden 2008). Striped bass are also tolerant of warmer temperatures, up to 31°C (88°F) (NDEP 2016). Aquatic invasive species have been documented to prey on steelhead, and to compete for habitat and food resources (Carey et al. 2011; Thompson et al. 2012).

Releases from the proposed low-level outlet under Alternative 1 are anticipated to maintain water temperatures similar to existing conditions. Overall, water temperature conditions for steelhead would continue to sometimes be suboptimal, but not lethal.

3.1.4 Fish Passage

HDR et al. (2021) identified two upstream passage alternatives at LPD for further consideration: Alternative U1 (technical fish ladder) and Alternative U8 (trap and transport – replace). HDR et al. (2021) also identified two downstream passage alternatives at LPD for further consideration: Alternative D1 (FSC – new) and Alternative D8 (spillway modification and FWC with 30 cfs attraction flow). These fish passage alternatives will be selected and adapted based on the selection of one of, or a combination of, the dam and reservoir alternatives and sediment management options selected for Los Padres. The following section considers the effects of each passage alternative. Full descriptions of each of the preferred fish passage alternatives are provided in HDR et al. 2021.

Upstream Passage

Under Alternative 1, upstream passage at LPD would continue to be operated as a managed fish passage facility. Based on the preferred alternatives selected in HDR et al. (2021), upstream fish passage could consist of either a technical fish ladder (Alternative U1) or a new trap-and-transport facility (Alternative U8).

A fish ladder would consist of an approximately 1,480-foot pool-and-weir type fish ladder comprising roughly 125 pools that would operate at flows ranging from 3 to 35 cfs (HDR et al. 2021). The installation of the fish ladder would involve a modification of the existing plunge pool to direct upstream migrating fish into the fish ladder. The fish ladder would provide volitional fish passage to upstream migrating adult steelhead, in which they would enter and navigate the ladder using their own swimming ability and behavioral cues, without human intervention. Although some juvenile steelhead might be able to use the ladder for upstream passage, the fish ladder would not be designed for juveniles and would generally be considered to block juvenile upstream passage for the purposes of this analysis.

Volitional fish passage is safer than trap and transport or other nonvolitional fish passage alternatives, and more effective at passing salmonids upstream of barriers (Lusardi and Moyle 2017). Implementation of this fish passage alternative, in conjunction with Alternative 1, would improve adult upstream fish passage conditions at LPD over existing conditions and would make passage conditions at LPD safer and more effective than under existing conditions. Under existing conditions, upstream migrating adult steelhead have been observed holding in the plunge pool below LPD, indicating that current fish passage facilities could be causing a delay in migration (HDR et al. 2021). The modification of the plunge pool to guide fish into the fish ladder could decrease the amount of time it takes to pass LPD and reduce migration delays associated with the fish passage facilities under existing conditions.

Although a fish ladder at LPD would provide volitional passage to upstream migrating adult steelhead, fish ladders have been shown to have lower relative effectiveness when passing fish at high-head dams (with hydraulic differential greater than 100 feet from entrance to exit), such as LPD (HDR et al. 2021). The length and complexity of a fish ladder at LPD has the potential to increase passage times and increase the amount of energy that upstream migrating steelhead would exert over existing conditions, which could potentially result in reduced fitness while spawning. Current examples of fish ladders at these types of dams have shown relatively low success at passing fish. Accordingly, NMFS and CDFW recognize that the performance of fish ladders may have limitations and that managers should be cautious of over-emphasizing the importance of volitional passage at the expense of overall performance (i.e., safe and timely passage of fish upstream). Additionally, this and the other managed passage alternative (Alternative U8) described below would block or impede juvenile steelhead rearing downstream of LPD from accessing stream habitat above LPR.

The new trap-and-transport alternative (Alternative U8) would replace the existing trap-and-transport facility with a larger facility aimed at accommodating the future recovery levels of steelhead in the Carmel River (HDR et al. 2021). The overall function of the facility would be similar to those under existing conditions, where fish would be attracted to a fish ladder entrance, enter and ascend the fish ladder to a small pool, and then either pass or be lifted into a large holding gallery and into a transport flume. Fish would then be transferred from the transport flume, conveyed into a transport vehicle, transported upstream of LPD, and released into LPR. The new trap-and-transport facility would modify the plunge pool to improve the guidance and attraction to the fish ladder entrance implement a new fish ladder designed in compliance with NMFS design guidelines, and use increased attraction flows. These components would likely increase the effectiveness of the fish passage facilities over existing conditions.

Trap-and-transport fish passage facilities are nonvolitional and require human intervention to pass fish upstream of LPD. Additionally, there would be no potential for kelts to navigate the same facility downstream (whereas a fish ladder could be one of several components potentially providing downstream passage—for example, along with a collector and the spillway). This fish passage alternative would require fish to be held in a holding flume for up to 24 hours before being transported upstream, which delays migration and increases stress and the risk of disease (Lusardi and Moyle 2017). Stress induced from trap and transport has been shown to reduce disease resistance, swimming ability, and osmoregulatory ability, and can increase pre-spawn mortality (Maule et al. 1988 as cited in Lusardi and Moyle 2017).

Downstream Passage

Under Alternative 1, upstream passage at LPD would continue to be operated as a managed fish passage facility. Based on the preferred alternatives selected in HDR et al. (2021), downstream fish passage facilities could consist of either an FSC (Alternative D1) or a spillway modification and the current FWC, with the addition of a 30 cfs attraction flow (Alternative D8). The effects of both alternatives on steelhead are evaluated below.

An FSC uses attraction flows and nets to guide downstream-migrating fish into a narrow channel that in turn guides fish into a collection inlet. Once in the collection inlet, downstream-migrating steelhead would remain in holding galleries until transferred to transport hoppers, barged to the dam crest, and then released into the tailwater pool through a water-to-water transfer down the existing smolt bypass pipe (HDR et al. 2021). The FSC in LPR would consist of full-depth guide nets and a floating barge, with attraction flows of up to 200 cfs; it would provide a barrier to inhibit passage of migrants downstream into the remainder of the reservoir. The FSC would be operated to coincide with the migration period of downstream-migrating steelhead and would operate 2 weeks past the end of the migration period to capture fish entering the reservoir.

The operation of the FSC and the attraction flows would alter the current water quality dynamics in LPR by causing mixing of the water column. Under existing conditions, LPR appears to be stratified; the mixing of the water column could destratify LPR, resulting in a reduction in the reservoir’s ability to maintain temperature stratification during the early summer. Elimination of stratification would increase water temperatures in the deeper portions of LPR, reducing the ability of the reservoir to provide rearing habitat during the early summer. Mixing may increase temperatures downstream of LPD during the same period, prior to late summer when stratification typically dissipates, and potentially causing seasonal impacts to fry and juvenile rearing habitat.

Stress from barge transportation of juvenile salmonids has been shown to increase predation levels after release, resulting in increased mortality (Lusardi and Moyle 2017). The presence of large piscivorous brown trout at the release location in the plunge pool below LPD could result in the predation of released juvenile steelhead.

Fish passage Alternative D8 involves a combination of actions, including modification to the existing spillway to provide safer and more effective downstream passage, and modifications to the existing FWC that would allow for attraction flows of 30 cfs. Modifications to the spillway would include a passage slot at the spillway crest to provide a larger opening for safer entrance and passage, and the implementation of an adjustable crest gate to control the depth and flow through the slot (HDR et al. 2021). Additional modifications to the spillway include a passage channel along the spillway, and modifications of the tailwater pool to improve safety during the transition from the spillway to the pool. Improvements to the FWC would improve the attraction to the entrance of the collector inlet. The existing FWC would be retrofitted to allow for up to 30 cfs of attraction flows and would route outmigrating steelhead directly to the existing smolt bypass pipe.

As with Alternative D1, fish passage Alternative D8 still involves the successful navigation of LPR by juvenile steelhead. Under existing conditions, Boughton et al. (2020) found that 75 percent of monitored downstream-migrating juveniles were "lost" in the reservoir, most likely from mortality (e.g., predation); remaining resident in the reservoir; or simply not being subsequently detected at downstream PIT tag antennae. Nonnative species have been documented in LPR and likely prey on *O. mykiss* in the reservoir. CDFW electro-fished upstream of LPR and observed brown trout up to 14 inches (Highland, pers. comm., 2017). A fish rescue and relocation effort conducted in the plunge pool below LPD captured 20 brown trout, five of which were larger than 20 inches (HDR et al. 2021). The capture of large brown trout downstream of LPR indicate they are likely using the reservoir and entering the lower watershed through the spillway. Brown trout are known predators of juvenile steelhead and likely account for a portion of the 75 percent of juvenile migrants lost in the reservoir reported in Boughton et al. (2020). For example, in Soda Springs Reservoir, a reservoir on the North Umpqua River that is similar in size to LPR, invasive brown trout were found to predate heavily on fry and juvenile salmonids moving through the reservoir (Stillwater Sciences 2019). Diet composition of larger brown trout (> 15 inches) contained primarily fish. This reservoir predation study found that brown trout had the greatest impact to migrating salmonids and consumed about half of juveniles produced upstream of the reservoir. If consumption rates of brown trout in LPR are similar, they are likely a primary source of mortality for migrating steelhead.

MPWMD (2015) concluded that a proportion of juvenile steelhead in the upper watershed (above LPR) enter LPR in the spring and use it as a rearing habitat until the following winter, when they migrate out as smolts. Additionally, LPR likely supports a small population of adfluvial steelhead, a life history in which steelhead migrate between stream and lake (reservoir) habitats to complete their life-history requirements, (Leitwein et al. 2016). LPR may influence the migration patterns of juvenile steelhead in several ways, including but not limited to serving as a rearing area or as a temporary holding area for smolts and juveniles fish that migrate into the reservoir from upstream rearing habitat; acting as a physical or biological barrier to downstream migration due to some thermal or water quality condition that impedes transit; and/or acting as a refuge for predators that consume smaller fish attempting to pass through the reservoir.

There remains a high level of uncertainty related to the transit, residualization, predation, and mortality in LPR (HDR et al. 2021). Without fully understanding the effect of LPR on downstream-migrating juvenile steelhead, it is difficult to ascertain how the modifications to the existing facilities will affect the steelhead population.

3.1.5 Summary of Alternative 1 Effects to Steelhead

Alternative 1 would result in the continuation of dynamics similar to those that occur under existing conditions, with a gradual or episodic reduction in storage over time. In general, Alternative 1 would provide higher summer flows than Alternative 2 (Dam Removal), flows capable of providing rearing habitat for both fry and juvenile steelhead downstream of LPD during the dry season in normal water years. Summer releases from LPD create suboptimal (due to high water temperatures) rearing conditions for steelhead in the reach just downstream of LPD; other areas of the Carmel River consistently provide more favorable temperature regimes for rearing steelhead. Notably, Alternative 1 would continue to block upstream movement of juveniles, thus continuing to prevent access to thermal refugia in the watershed upstream of LPR. The frequent dry back that occurs in the lower 9 miles of the Carmel River would likely continue under Alternative 1, but to a lesser extent than would occur in the absence of LPR. Water availability would decrease as LPR continues to fill in with sediment, leading to increased dry back and a reduction in summer rearing habitat downstream of LPD over time.

In the absence of appropriate mitigation, Alternative 1 would result in the continued blockage of all of the sediment bedload and a portion of the suspended load, and thus incision of the channel downstream of LPD to the former San Clemente Reservoir area. This in turn would result in decreased habitat suitability for steelhead and further limit the quantity and quality of spawning habitat downstream of LPD in Reach 1 and a portion of Reach 2. Downstream of Reach 2, sediment transport and depositional rates are highly dependent on the recent reintroduction of bedload supply from the reach between the former San Clemente Dam and LPD.

Under Alternative 1, upstream passage facilities at LPD would consist of either a technical fish ladder or a new trap-and-transport facility. Both options would continue to provide upstream passage for adults and support the anadromous population. However, neither option favors juvenile upstream movement and, relative to full volitional passage, both options have potential to increase stress and migration delay for migrating adult steelhead.

Downstream passage facilities under Alternative 1 could consist of an FSC or a modification of the existing spillway and current FWC system. Both preferred downstream fish passage alternatives would result in nonvolitional fish passage, would continue to subject downstream-migrating juveniles to mortality in LPR, and would potentially favor resident and adfluvial over anadromous life histories. Although these options would be an improvement over existing conditions, dam removal is the only alternative that can provide complete volitional passage and provide safer and more effective migration.

3.2 Alternative 2 (Dam Removal)

Alternative 2 includes full dam removal (Alternative 2a) and partial dam removal (Alternative 2b). These alternatives are described in detail in the Alternatives Descriptions TM (AECOM 2017b). Both full dam removal and partial dam removal result in the same outcome for the key drivers of steelhead habitat dynamics, including volitional fish passage, sediment transport, and water availability. Therefore, the effects of the two subalternatives are described in the following section together, as Alternative 2.

3.2.1 Suspended Sediment

Alternative 2 would be implemented after the fine sediment in Zones 1 and 2 of LPR is removed via dredging or sediment management option SM-3 (Sluicing Tunnel). A full evaluation of the effects of suspended sediment, resulting from SM-3, on steelhead and steelhead habitat is discussed below in Section 3.5.3, Sluicing Tunnel (SM-3).

3.2.2 Bedload Sediment Transport

Alternative 2 would result in a significant increase in sediment supply to downstream reaches, which could have substantial effects on steelhead habitat. With the removal of LPD, bed elevations along channel reaches downstream are generally expected to increase through sediment transport and deposition of primarily coarse sand, gravels, and cobbles (0.5 to 256 mm); this is the expected response because downstream reaches have received less sediment than that found under natural conditions since the dam was constructed (AECOM 2017b). Bed aggradation would begin with the first storms that generate runoff capable of mobilizing portions of the coarse sediment wedge in the reservoir. In general, the most rapid rates of aggradation occur with the first several storms following dam removal and taper off into the future years after these events. However, an aggradational signal in reaches most downstream of the dam would be delayed because it takes time for sediment to arrive at these reaches. Redistribution of gravel-sized coarse sediment to reaches downstream of LPD is expected to increase the amount of available steelhead habitat. Sediment supply in the former LPR would decrease rapidly following dam removal, depending on hydrologic conditions,

The BESMo (Balance Hydrologics and UBC Geography 2019) predicts that, under Alternative 2, more than 22 feet of aggradation would occur just downstream of LPD following dam removal due to the reintroduction of sediment supply. Fining of the bed would occur close to LPR, resulting from the increased supply of relatively fine sediment. Aggradation response lessens downstream, but aggradation up to 9 feet is estimated to occur at the former San Clemente Reservoir backwater zone. Downstream of the former San Clemente Dam, the model predicts up to 13 feet of sediment deposition and a steady decrease in deposition occurring at Hitchcock Creek. Within 10,000 feet upstream and downstream of the Garzas Creek confluence, the model predicts 2 feet of erosion. Downstream of this zone of erosion, the model predicts relatively constant levels of aggradation of up to 5 feet. The model indicated that the redistribution of sediment downstream of LPD under Alternative 2 is likely to occur independently of hydrologic conditions.

Under Alternative 2, the bed downstream of LPD is predicted to coarsen as a response to deposition and the resultant increase in bed slope. Only in the results for Year 10 of the dry hydrologic condition does the median grain size just below LPD decrease slightly from its existing size, later coarsening as shown in Years 30 and 60 (Balance Hydrologics and UBC Geography 2019). Resumption of the historical supply and the addition of accumulated sediment from LPR would prevent the further coarsening of the bed downstream of the former San Clemente Dam (Balance Hydrologics and UBC Geography 2019). An increase in upstream sediment supply would cause increased sediment mobility and bed mixing. The redistribution of gravel-sized coarse sediment to reaches downstream of the dam would increase the quantity and quality of the available steelhead spawning habitat. The rapid supply of sediment downstream would alter the current dynamics of the river on a reach scale, including the loss of gravel bars, pools, and riffles; and would enhance sediment supply in low-velocity areas, the floodplain, and backwater areas (Pizzuto 2002). However, areas in the active channel that could temporarily be inundated by sands and small gravels would likely see fining within a relatively short period (i.e., a few years). Upstream of the former dam site, the channel would incise into the Zone 3 sediment upstream of LPD and rapidly redistribute this sediment downstream.

After the removal of the San Clemente Dam, the primary geomorphic response downstream of the former dam was sediment deposition in pools and runs, with limited to no bed-elevation changes in riffles (NMFS 2018). Spawning gravel availability was increased near the former dam site; a loss in suitable spawning habitat occurred farther downstream of the dam, likely due to the transport of finer substrates (Ohms and Boughton 2019).

Short-term impacts include a reduction in pool habitat due to sediment deposition. This results in decreased rearing habitat, especially in the summer as pool depths become shallow due to decreased flows. However, in the medium to long term, restoration of annual sediment load would result in increased sediment supply and would benefit steelhead spawning habitat by introducing coarse-sized gravels to gravel-starved reaches downstream of the former dam. The effects of bedload deposition would last weeks or years, depending on the ability of subsequent erosive flows to scour or clean the substrate. For example, pools closest to the dam could be scoured out in 1 to 3 average years, whereas pools farther downstream could take several years to scour out, depending on hydrology. However, bedload supply and transport are vital to the creation and maintenance of functional aquatic habitat. Natural river dynamics include transportation of coarse sediment (e.g., sand, gravel, cobble, and boulder) downstream. The aggradation of the bed and increased sediment supply would increase channel complexity and floodplain access, resulting in increased habitat for all steelhead life stages.

3.2.3 Water Availability

As described in detail in Section 2.4.2.2 of the Study Preparation TM (AECOM 2017a) and summarized in Section 2.1.1 of the Alternatives Descriptions TM (AECOM 2017b), releases from LPR are used to augment dry season flows in the Carmel River. During dry periods, releases from LPR typically constitute more than 50 percent and as much as 90 percent of the flow in the river downstream of LPD (Cal-AM and MPWMD 2016). More than 90 percent of the average annual precipitation in the watershed typically occurs between November and April, with the highest rainfall amounts occurring in January and February

(Entrix 2008). Inflows to LPR are generally lower for the rest of the year, from May to October. Inflow to LPR is measured once a month by MPWMD upstream of LPD (MPWMD 2008). Figure 14 shows instantaneous inflow, measured by MPWMD once each month from June through December, for years in which inflow fell below 5 cfs during at least 1 month. Figure 15 shows inflows for years in which inflow never fell below 5 cfs. Together, these figures show that for a little more than two thirds of years between 1990 and 2021, inflow to LPR fell below 5 cfs for a few months of the year.

Under Alternative 2, dry season flow releases from LPR would be eliminated and natural daily, seasonal, and annual flow variability would increase. Restoration of the hydrologic function of the Carmel River system under Alternative 2 is predicted to result in an overall decrease in flows during the dry season, and thus a substantial decrease in the quantity of existing steelhead habitat in the Carmel River. Drying of the channel during summer months, which currently occurs most years in a portion of the Carmel River downstream of the Narrows (RM 8), is predicted to be extended across a greater length of stream and for a greater duration.

Based on the CRBHM flow exceedance curves (Figure 12 and Figure 13), stream flows under Alternative 2 from July through September are predicted to be significantly less than those under existing conditions (or under Alternatives 1, 3, and 4). During the summer, the absence of releases from LPD is predicted to significantly reduce flows capable of providing suitable fry rearing habitat (>3 cfs) throughout most of the Carmel River downstream of LPD—with most suitable habitat occurring in Reach 2 downstream of the confluence with Garzas Creek (Figure 1). Based on the CRBHM model results and IFIM habitat suitability predictions, minimum summer flows to support juvenile rearing habitat (> 5 cfs) are expected to be greatly reduced across all locations under Alternative 2 (Figure 7). At Highway 1 (Figure 12), 3 cfs is predicted to be exceeded 12 percent of the time during all water years under Alternative 2, and 4 percent during dry and critically dry years (Figure 13). Similarly, 5 cfs is predicted to be exceeded 8 percent of the time during all water years, and 2 percent during dry and critically dry years (Figure 13) at Highway 1. This represents a 60 percent reduction in exceedance of 3 cfs during all water years, and a 42 percent decrease in exceedance of 5 cfs, when compared with Alternative 1 (Figure 13). Overall, Alternative 2 is predicted to provide the shortest duration of suitable habitat for fry and juvenile steelhead when compared to other alternatives (Figure 8 and Figure 9).

Based on the CRBHM flow extent figures (Figure 5 through Figure 7), under Alternative 2 during in water years, approximately 20 miles of the Carmel River downstream of LPD is projected to be wetted (> 0.5 cfs) in the summer, with a substantial increase in dry back predicted in the lower Carmel River (Figure 5). This is a 4.5-mile reduction in the predicted length of wetted habitat in the summer under Alternative 2 when compared with Alternative 1. Under Alternative 2, in the summer in normal water years, flows of 3 cfs are predicted to occur in approximately 7.5 miles of the Carmel River, a reduction of 17 miles when compared with Alternative 1 (Figure 6). Under Alternative 2, the CRBHM predicts that flows of 5 cfs in the summer of normal water years would not occur in the Carmel River, which is a reduction of 21 miles when compared with Alternative 1 (Figure 7).

Low summer flow has been associated with decreased survival of juvenile steelhead (Grantham et al. 2012; Hwan et al. 2017); as juvenile steelhead migrate to the ocean, low flows and high-water temperatures can directly impact downstream mortality and indirectly affect nearshore mortality (Ohms et al. 2021). Overall, the predicted reduction in flow would cause a significant reduction in available fry and juvenile rearing habitat. Additionally, the area prone to dry back is expected to extend farther upstream under Alternative 2 than under Alternatives 1, 3, and 4. Based on MPWMD-observed densities of steelhead reported in Ohms et al. (2021), the increased dry back could reduce habitat for more than 2,000 rearing steelhead in a normal water year in the lower Carmel River. Figure 16 shows the extent of seasonal and perennial rearing habitat, as well as barriers to steelhead migration, in the Carmel River watershed. MPWMD (Christensen, pers. comm., 2021) notes that several tributaries shown in Figure 16 as perennial rearing habitat are sometimes dry (or are intermittent) near their confluences with the mainstem Carmel River, including Robinson Canyon, San Clemente, Pine, and Danish Creeks, and maybe Miller Fork, but the map serves as a reasonable approximation of rearing habitat distribution in the watershed. As discussed in Section 3.1.2, the lower reaches of the Carmel River apparently support the fastest observed growth of juvenile steelhead, so a decrease in rearing habitat and an increase in dry back in the lower reach could reduce the production of anadromous steelhead in the Carmel River watershed (Ohms and Boughton 2019).

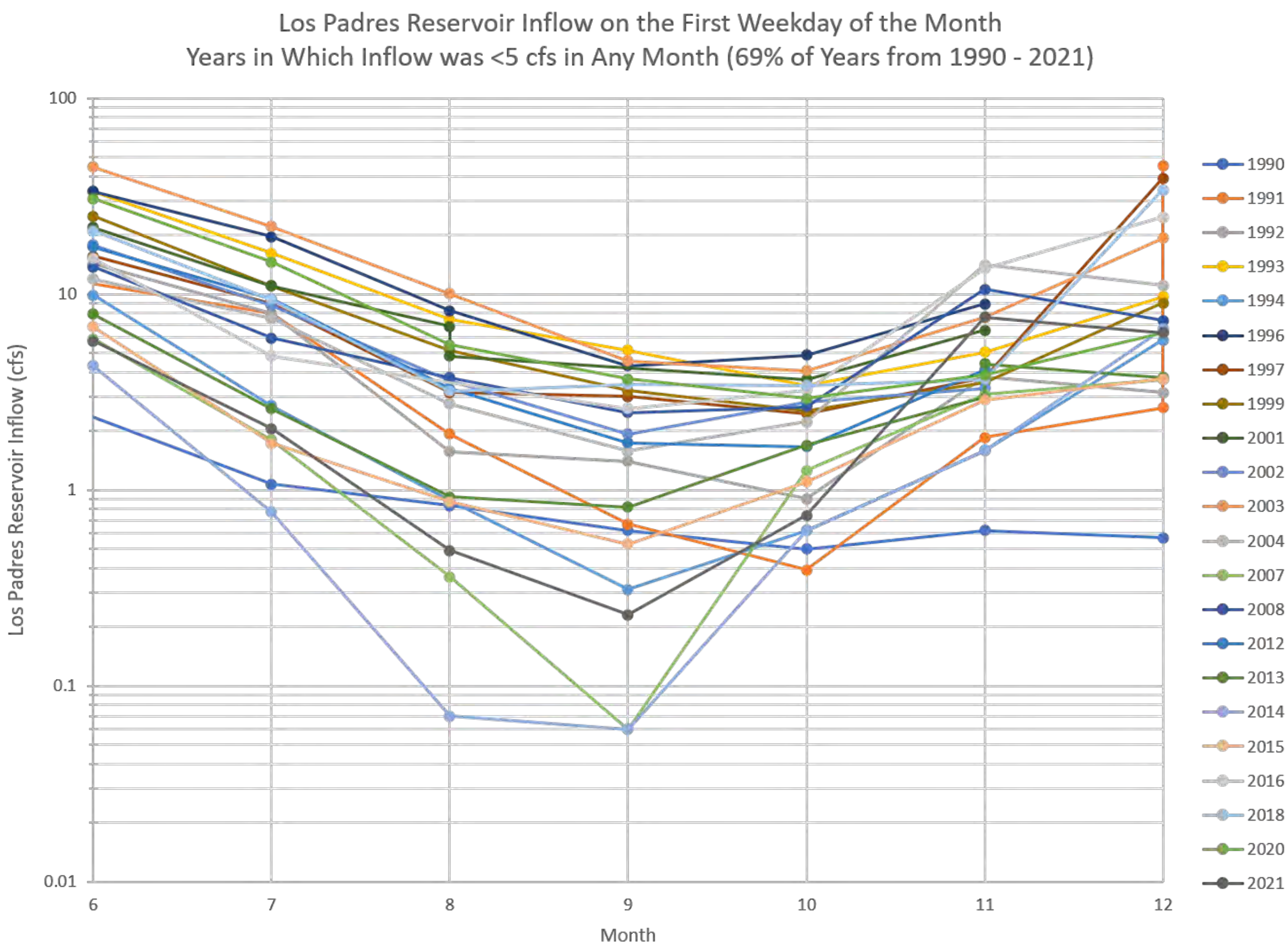


Figure 14 Carmel River Inflow (cfs) to Los Padres Reservoir during Years in which Inflow Fell Below 5 cfs

Source: MPWMD unpublished data

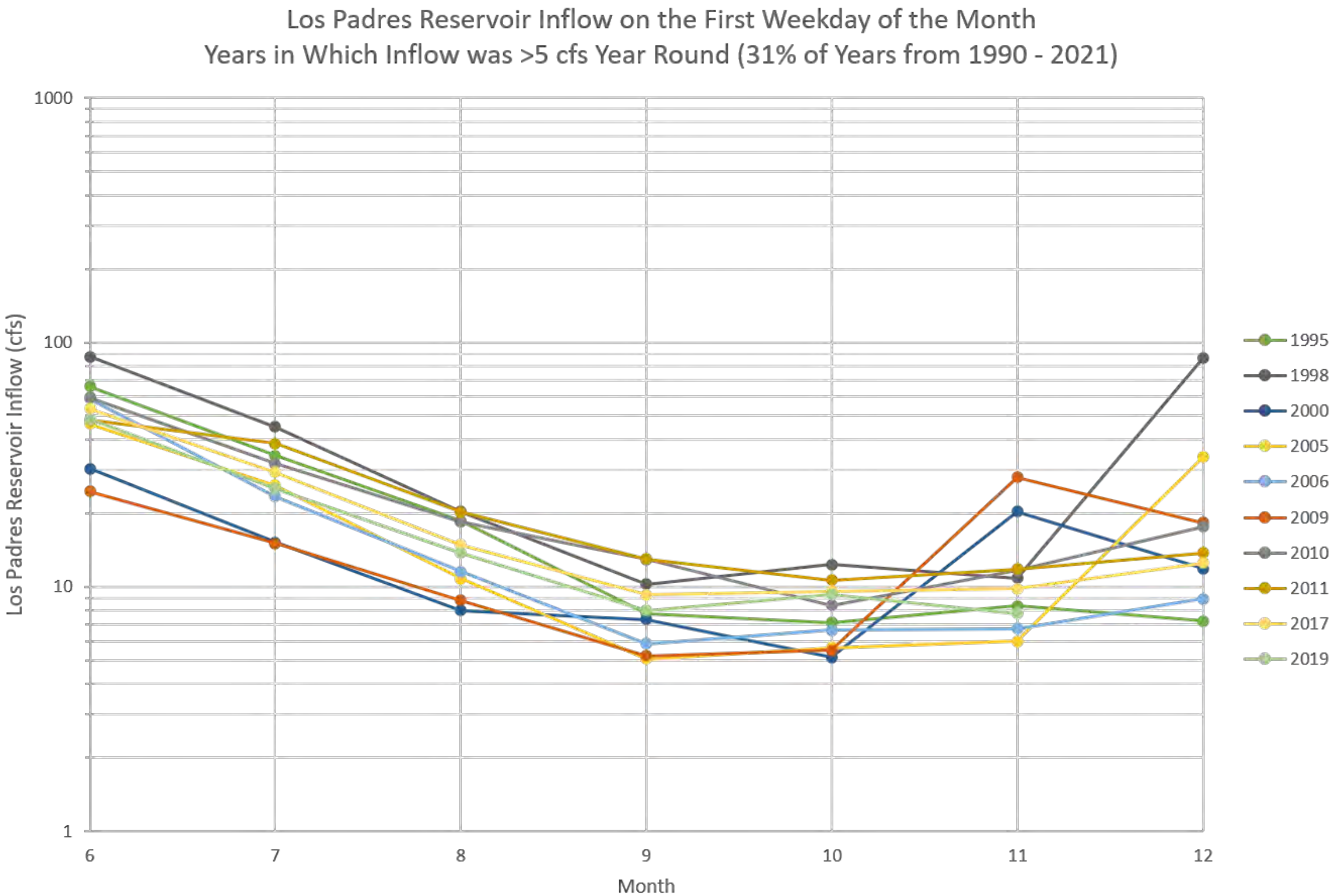
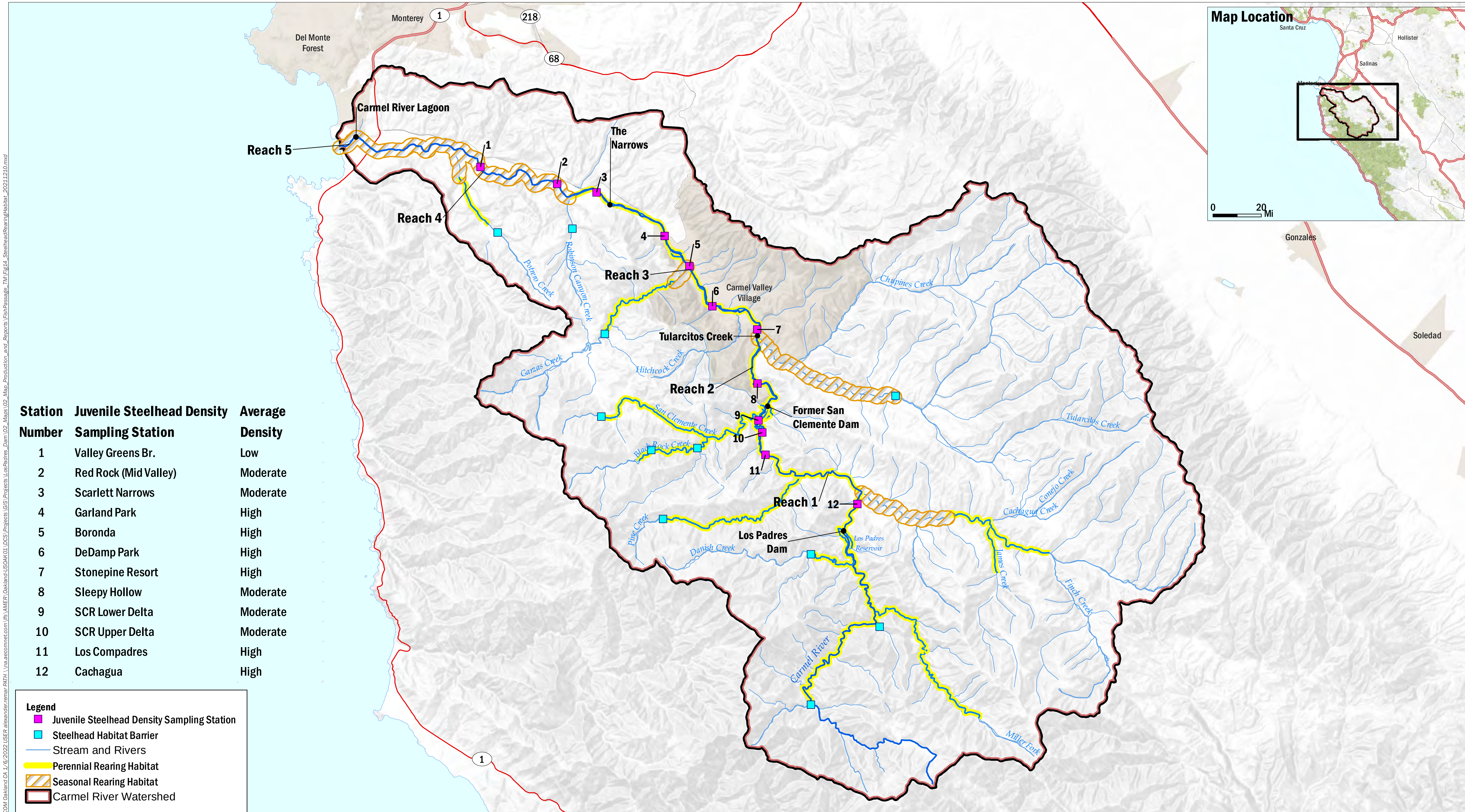


Figure 15 Carmel River Inflow (cfs) to Los Padres Reservoir during Years in which Inflow did not Fall Below 5 cfs

Source: MPWMD unpublished data



Station Number	Juvenile Steelhead Density Sampling Station	Average Density
1	Valley Greens Br.	Low
2	Red Rock (Mid Valley)	Moderate
3	Scarlett Narrows	Moderate
4	Garland Park	High
5	Boronda	High
6	DeDamp Park	High
7	Stonepine Resort	High
8	Sleepy Hollow	Moderate
9	SCR Lower Delta	Moderate
10	SCR Upper Delta	Moderate
11	Los Compadres	High
12	Cachagua	High

N
0 5 10
Miles

AECOM, 2021
MPWMD, 2004, 2014
CPAD, 2020
ESRI Basemap, 2021

AECOM

Monterey Peninsula Water Management District

Los Padres Dam and Reservoir Alternatives and Sediment Management Study

FIGURE 16

Steelhead Rearing Habitat

3.2.4 Water Temperature

Alternative 2 would eliminate releases from LPR and restore a more natural thermal regime to the Carmel River. Under existing conditions, water temperatures upstream of LPR are generally cooler than locations in and downstream of LPR (MPWMD 2020). With the removal of LPD, juvenile steelhead rearing in Reach 1 would have the opportunity to move upstream to locate thermal refugia, and water temperatures immediately downstream of LPD would be cooler than under existing conditions in the summer and fall months. The elimination of warm water releases from LPR would likely decrease water temperatures in downstream reaches; however, the area around the San Clemente Reroute Project is subject to suboptimal water temperatures under existing conditions, likely due to a lack of riparian vegetation. Temperatures in this reach may therefore remain suboptimal until the riparian cover matures (MPWMD 2019).

As discussed in Section 2.4, Water Temperature, and in AECOM (2017a), in some months (e.g., April), water temperatures consistently warm as water moves downstream from LPD, but in other months (e.g., September), water temperatures fluctuate as water moves downstream. Since the removal of San Clemente Dam, summer water temperatures downstream of the former dam site appear slightly cooler, and winter temperatures appear slightly warmer (MPWMD 2020). Similar trends may be observed following the implementation of Alternative 2 due to the elimination of releases from LPR.

The effects of the removal of LPD on water temperature would likely be most beneficial in the reach just downstream of LPD, where, under existing conditions, water temperatures are currently suboptimal for rearing steelhead. This reach would benefit from a more natural thermal regime, providing benefits to rearing steelhead by providing optimal water temperatures. However, although the removal of LPD would result in a more natural thermal regime in the Carmel River, resulting in cooler water temperatures in the reaches just downstream of LPD, the reduction in flow in the summer months would likely result in an overall decrease in rearing habitat when compared with existing conditions.

3.2.5 Fish Passage

Alternative 2 would result in fully volitional upstream and downstream passage for all steelhead life stages, increasing the likelihood of successful passage to the upper and lower watershed. Under existing conditions, LPD currently impedes the upstream migration of adult steelhead and the downstream migration of juvenile steelhead from the upper watershed. Additionally, LPD completely blocks the upstream movement of juvenile steelhead to the upper watershed, preventing access to suitable rearing habitat, and especially to cool water that would offer thermal refugia during late summer and fall.

Based on a review of trap-and-haul programs, Lusardi and Moyle (2017) concluded that trap and haul can be a successful conservation strategy for anadromous salmonids, but the process can cause substantial levels of stress to steelhead, which can lead to increased pre- or post-spawn mortality of adult steelhead. Adult and juvenile fish have been observed using the spillway to migrate downstream, which presumably results in a greater occurrence of injury than under a no-dam condition (Boughton 2016). Compared with fish passage facilities and conditions under Alternatives 1, 3, and 4, Alternative 2 would provide the safest and most effective fish passage opportunities for all life stages of steelhead in the Carmel River watershed.

Dam removal and restoration of the stream channel currently inundated by LPR would provide roughly 14.4 additional RMs of habitat for juvenile steelhead and resident *O. mykiss* whose access was blocked by LPD (Becker et al. 2010). The Carmel River upstream of LPR provides drought refugia to rearing steelhead. If steelhead were able to access this refugia habitat during drought years, it would increase the resiliency of the Carmel River steelhead population, especially during a warming climate. LPD currently interrupts the thermal regime of the Carmel River, resulting in suboptimal water temperatures downstream of the dam and a cold-water habitat upstream of LPR, which is inaccessible to steelhead rearing downstream of LPD. Willis et al. (2021) suggests that improving passage to juvenile salmonids or full dam removal are critical to reconnect species with the thermal regimes in which their life-history strategies originally evolved.

A wide distribution within a watershed is a critical element of steelhead population resiliency because it reduces the susceptibility of the population to catastrophic disturbance in one portion of the watershed (Lindley et al. 2007; Reeves et al. 1995). Currently, juvenile steelhead rearing downstream of LPD do not have access to habitat upstream of LPR. Furthermore, the hydrology of the watershed makes it likely that the habitat in the Carmel River and tributaries upstream of LPR were historically among the most productive in the watershed. Instead, under present conditions, Carmel River downstream of LPD is subject to warming from LPR, in a pattern similar to many managed watersheds in California (Willis et al. 2021). Dam removal under Alternative 2 would increase the resiliency of the steelhead population in the watershed by increasing unimpeded volitional passage, especially for juveniles. Alternative 2 would eliminate reservoir habitat on the Carmel River, restoring the approximately 1-mile section of river currently inundated by LPR to a natural stream. LPR currently has deleterious effects on downstream-migrating juvenile steelhead, with a large proportion of downstream migrants “lost” while migrating through the reservoir (Boughton et al. 2020). The removal of LPD would eliminate the reservoir and increase the likelihood of successful downstream passage of juvenile steelhead.

It is speculated that LPR likely supports a population of adfluvial steelhead, in which steelhead migrate between stream and lake (reservoir) habitats to complete their life-history requirements (CDFG 1995; Leitwein et al. 2016). The elimination of reservoir habitat would prohibit an adfluvial life-history strategy for the current population, and individuals would either exhibit a resident or anadromous life history. Based on PIT tag monitoring data to date (Ohms and Boughton 2021), the likely result would be an increase in anadromous smolt production from the upper watershed.

3.2.6 Summary of Alternative 2 Effects to Steelhead

Restoring natural sediment transport under Alternative 2 would result in an overall increase in the amount of suitable spawning gravel downstream of LPD when compared with Alternative 1. Alternative 2 would also have impacts to steelhead habitat, resulting from increased bedload movement from upstream of LPD in the short term, including the loss of pool habitat due to bedload deposition. However, this effect would be short-lived and, in the long term, Alternative 2 would increase channel complexity and limited overbank habitat connectivity, resulting in an increase in stream habitats that support steelhead fry and juvenile rearing.

Although instream habitat complexity would increase under Alternative 2, the loss of summer flow releases from LPR is predicted to result in a substantial decrease in flows capable of providing adequate rearing habitat for steelhead—and a substantial reduction in wetted stream, especially during dry years. Dry season diversions by riparian and appropriative water rights holders throughout the watershed likely reduce flow to the main stem that would otherwise provide summer rearing habitat.

Of all the project alternatives, Alternative 2 provides for the safest and most efficient steelhead upstream and downstream passage, providing fully volitional upstream and downstream passage for all life stages of steelhead. Adult upstream migration would be unimpeded by LPD and could result in the passage of more adult fish to the upper watershed when compared to Alternatives 1, 3, and 4. Additionally, juvenile steelhead mortality currently presumed to occur under existing conditions in LPR would be significantly reduced after the removal of LPD. Juvenile downstream migrants would experience less predation and mortality than under the other project alternatives, resulting in a potential increase in smolt production in the Carmel River, which would better support an anadromous life history.

Alternative 2 would also increase the amount of habitat for juvenile steelhead and resident *O. mykiss* rearing in the Carmel River through the restoration of approximately 1 mile of stream habitat in the former LPR reach. Additionally, juvenile steelhead and resident *O. mykiss* rearing downstream of LPD would be provided year-round access to the upper watershed, which currently provides suitable rearing habitat and optimal temperatures for rearing steelhead throughout the year.

3.3 Alternative 3 (Restore Reservoir Capacity)

Under Alternative 3 (Restore Reservoir Capacity), reservoir capacity would be increased in LPR by dredging sediment from the existing reservoir and disposing of the sediment on land. Alternative 3 is described in detail in the Los Padres Dam and Reservoir Alternatives and Sediment Management Study TM (AECOM 2017b). Although not specifically described in the TM, if desired, this alternative could later be paired with a sluice tunnel to remove fine sediment prior to dam removal.

3.3.1 Bedload Sediment Transport

Under Alternative 3, effects on downstream channel geometry and sediment transport, and their effects on steelhead and steelhead habitat, would be similar to those described in Section 3.1.1 for Alternative 1, where LPD continues to interrupt sediment transport on the mainstem Carmel River.

3.3.2 Water Availability

Restoring LPR to its original capacity under Alternative 3 would provide an additional 1,108 AF of storage, resulting from removing the accumulated sediment from the reservoir. This increased capacity would provide an additional average release from LPD of about 3 cfs (6.1 AF) per day during the 6-month dry season period. Restoring the reservoir capacity to the original capacity would also create new water right allocations and would allow for additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit.

Although reservoir storage is increased under Alternative 3, flows from July through September are predicted to be similar to those under Alternative 1, due to the increase in water right allocations and pumping in the lower river. Based on the CRBHM flow exceedance curves, under Alternative 3, minimum flows to support juvenile rearing habitat (> 5 cfs based on IFIM predictions) occur in the summer upstream of Reach 4 in most years. Based on the CRBHM flow exceedance curves (Figure 12), in the summer at Highway 1, 3 cfs is predicted to be exceeded 84 percent of the time during all water years and 50 percent of the time during dry and critically dry years (Figure 13). Similarly, 5 cfs is predicted to be exceeded 50 percent of the time during all water years (Figure 12), and 22 percent of the time during dry and critically dry years (Figure 13), at Highway 1 in the summer. These exceedance values are similar to those described under Alternative 1, with the exception that Alternative 3 is predicted to result in a 12 percent increase over Alternative 1 in the amount of time flows > 3 cfs are achieved in the summer during average years at Highway 1. This predicted increase in flows over Alternative 1 would result in more wetted habitat in the lower reaches of the Carmel River in the summer, which has the potential to bolster the anadromous steelhead production in the Carmel River watershed compared to Alternative 1. Based on CRBHM and IFIM predictions, Alternative 3 provides a duration of suitable habitat for fry and juvenile steelhead in the summer similar to that experienced under Alternatives 1 and 4, while providing substantially greater duration of suitable habitat downstream of LPD than would be experienced under Alternative 2 (Figure 8 and Figure 9).

Based on the flow extents predicted by the CRBHM (Figure 5 through Figure 7), under Alternative 3, the Carmel River would be wetted (> 0.5 cfs) in the summer months from LPD downstream to the lagoon (around 25 RMs) in normal water years (Figure 5). Flows of 3 cfs in the Carmel River are also predicted to occur in the summer months of normal water years, downstream of LPD to the lagoon, under Alternative 3 (Figure 6). These figures also indicate that flows of 5 cfs are predicted to occur during summer months in approximately 23 miles of the Carmel River in normal water years under Alternative 3, an increase of 2 miles when compared with Alternative 1 (Figure 7).

3.3.3 Water Temperature

Alternative 3 is unlikely to affect water temperature releases relative to existing conditions; conditions under Alternative 3 would be similar to the conditions described for Alternative 1 above.

3.3.4 Fish Passage

Effects of Alternative 3 on steelhead upstream and downstream passage would be similar to those described under Alternative 1 in Section 2.5, Fish Passage.

3.3.5 Summary of Alternative 3 Effects to Steelhead

Alternative 3 is predicted to provide increased summer flows capable of providing adequate rearing habitat for both fry and juvenile steelhead throughout the dry season when compared with existing conditions and Alternative 1. The increase in flows under Alternative 3 is predicted to increase the duration of flows providing suitable rearing habitat for fry during the dry season at Highway 1 by 12 percent, relative to Alternative 1. The frequent dry back that occurs in the lower 9 miles of the Carmel River would likely continue under Alternative 3; however, the additional releases of 3 cfs per day from LPD during the dry season would likely reduce the amount of dry back under existing conditions and keep the dry back area from extending higher up the Carmel River.

Alternative 3 would result in the continued incision of the channel downstream of LPD, resulting in decreased habitat complexity and a continued lack of access to overbank habitat. Additionally, the lack of upstream gravel recruitment would continue to limit the quantity and quality of spawning habitat downstream of LPD.

Under Alternative 3, upstream passage facilities at LPD would consist of either a technical fish ladder or a new trap-and-transport facility. Both options would continue to provide upstream passage for adults and support the anadromous population. However, neither option favors juvenile upstream passage and, relative to full volitional passage, both options have potential to increase stress and migration delay for migrating steelhead.

Downstream passage facilities under Alternative 3 could consist of an FSC or a modification of the existing spillway and current FWC system. Both preferred fish passage alternatives would result in nonvolitional fish passage, would continue to subject downstream-migrating juveniles to mortality in LPR, and may favor resident and adfluvial life histories over anadromy. Although these options would be an improvement over existing conditions, complete volitional passage (i.e., dam removal) would provide safer migration.

3.4 Alternative 4 (Storage Expansion)

Under Alternative 4 (Storage Expansion), the storage capacity of LPR would be increased through modification of the height of the existing dam (with a rubber dam[3]) and by dredging to accommodate the original storage capacity. This alternative would increase storage capacity by 1,694 AF. Like Alternative 3, although not specifically described in the Alternatives Descriptions TM, this alternative could, if desired, later be paired with a sluice tunnel to remove fine sediment prior to dam removal.

3.4.1 Bedload Sediment Transport

Effects of bedload resulting from Alternative 4 would be similar to those described under Alternative 1 in Section 3.1.1, Bedload Sediment Transport.

3.4.2 Water Availability

Given the small capacity of the LPR, Alternative 4 would not have a significant impact on instream flows during the precipitation season. However, the additional 1,694 AF of storage would allow additional average releases of 4.6 cfs (9.3 AF) per day during the 6-month dry season period. Increasing the reservoir capacity would also create new water right allocations and would allow for additional pumping in the Carmel River Basin above the 3,376 AFY CDO limit. Increased summer flow releases would increase both the quality and quantity of summer rearing habitat for steelhead downstream of LPD by increasing flows through existing rearing habitat and by wetting portions of the channel that currently dry out in summer months.

Based on the CRBHM model results, stream flows from July through September under Alternative 4 are predicted to be greater than under any other dam and reservoir alternative. During the summer, the

[3] The Alternatives Descriptions TM (AECOM 2017b) describes two subalternatives that differ in the method of increasing the storage capacity of LPD. However, based on TRC review of that TM, the option that includes a rubber dam is the one that will be carried forward into alternatives development. This decision will be described in the forthcoming Alternatives Development TM.

increased flow releases from LPD would significantly increase suitable fry and juvenile rearing habitat throughout the Carmel River downstream of LPD. Alternative 4 is predicted by the IFIM to provide a greater duration of suitable habitat for fry and juvenile steelhead than Alternatives 3 and 4, while providing a substantially greater duration of suitable habitat than Alternative 2 (Figure 8 and Figure 9). Based on the CRBHM flow exceedance curves, minimum flows predicted by the IFIM to support juvenile rearing habitat (> 5 cfs) are expected to be met more than 90 percent of the time during the dry season downstream of LPD and near the location of the former San Clemente Dam in Reach 2 (Figure 1), in both average and dry and critically dry water years. The CRBHM flow exceedance curves indicate that at Highway 1 (Figure 12), in the summer, 3 cfs is predicted to be exceeded 90 percent of the time in all water years and 58 percent of the time in dry and critically dry years (Figure 13). Similarly, 5 cfs is predicted to be exceeded at Highway 1 82 percent of the time in all water years (Figure 12) and 48 percent of the time in dry and critically dry years (Figure 13). The increase in water during the dry season would likely reduce the amount of dry back currently experienced in the lower Carmel River. This would result in increased rearing habitat availability for steelhead in the lower watershed, which apparently supports the fastest observed growth of juvenile steelhead in the watershed (Boughton and Ohms 2018),

Under existing conditions, up to 9 miles of habitat in the lower Carmel River are seasonally subjected to dewatering—depending on the magnitude of streamflow releases at LPD, seasonal air temperatures, and water demand. Water availability under Alternative 4 would be the greatest out of all alternatives. Under Alternative 4, in normal water years, the Carmel River is predicted to be wetted (> 0.5 cfs) from LPD downstream to the lagoon in the summer months (Figure 5). This increase in wetted habitat would reduce dry back associated with the summer months in dry years and provide the maximum amount of wetted habitat downstream of LPD when compared with other alternatives. Based on the CRBHM flow predictions shown in the figures, under Alternative 4, flows of 5 cfs would occur in summer months of normal water years throughout the Carmel River, from LPD downstream to the lagoon (Figure 7). This increase in wetted habitat and increased flows during the dry season would benefit the quantity and quality of existing steelhead rearing habitat. By increasing available rearing habitat in the lower Carmel River, Alternative 4 has the potential to boost juvenile steelhead production in the Carmel River watershed compared to existing conditions, and would provide the greatest amount of wetted habitat when compared to other dam and reservoir alternatives.

3.4.3 Water Temperature

Alternative 4 is not likely to increase cold water storage in LPR, and the temperature of released water is anticipated to be similar to existing conditions, as described for Alternative 1 above.

3.4.4 Fish Passage

Effects of Alternative 4 on steelhead upstream and downstream passage would be similar to those described under Alternative 1 in Section 3.1.4. Under existing conditions, HDR et al. (2021) identified LPR as having an influence on the migration patterns of juvenile steelhead, including acting as a physical or biological barrier to downstream migration due to some thermal or water quality condition that impedes transit. Alternative 4 would result in a larger, deeper reservoir, which has the potential to further impede the successful migration of juvenile steelhead. As discussed in Section 3.1.4, brown trout predation in LPR could be a significant cause of mortality for juvenile steelhead, and an increase in the size of the reservoir has the potential to increase the population size of brown trout, thus increasing the risk of predation of juvenile steelhead. The increase in reservoir size would increase transit time, which could further decrease anadromous production and increase the risk of predation, injury, or mortality (Ohms and Boughton 2021; HDR et al. 2021).

Although not strictly related to fish passage, there is a unique aspect of Alternative 4 that may warrant additional consideration. Field biologists have noted abundant spawning-sized gravels immediately upstream of the original head of LPR, raising the question of whether *O. mykiss* redds in this reach could be inundated if a rubber bladder is raised to increase storage (Ohms and Hamilton, pers. comm., 2021). Observers report that these gravels begin approximately at the location of the original, 1947 head of reservoir (prior to sediment accumulation that reduced the upstream extent of the reservoir pool) and continue upstream for about 3,000 feet of the Carmel River channel, roughly to station 12+00 in

Figure 17. AECOM (2018) observed deposition at the upstream end of the reservoir, above the high reservoir pool elevation, but that sediment characterization study did not extend far upstream of the 1947 pool. Relatively coarse sediment deposition upstream of a reservoir is not uncommon, due to reductions in water velocities during flood conditions as a stream approaches a reservoir; some of these deposits probably formed because of the reservoir. Anecdotally, limited *O. mykiss* spawning has been observed in this reach, although spawning has frequently been observed farther upstream in smaller gravel patches in boulder-dominant reaches (Ohms and Hamilton, pers. comm., 2021). Based on these observations and the questions raised, for alternatives that include a rubber bladder dam, it may be necessary to consider the extent and timing of backwatering that would occur upstream of the current reservoir pool, relative to *O. mykiss* spawning activity.

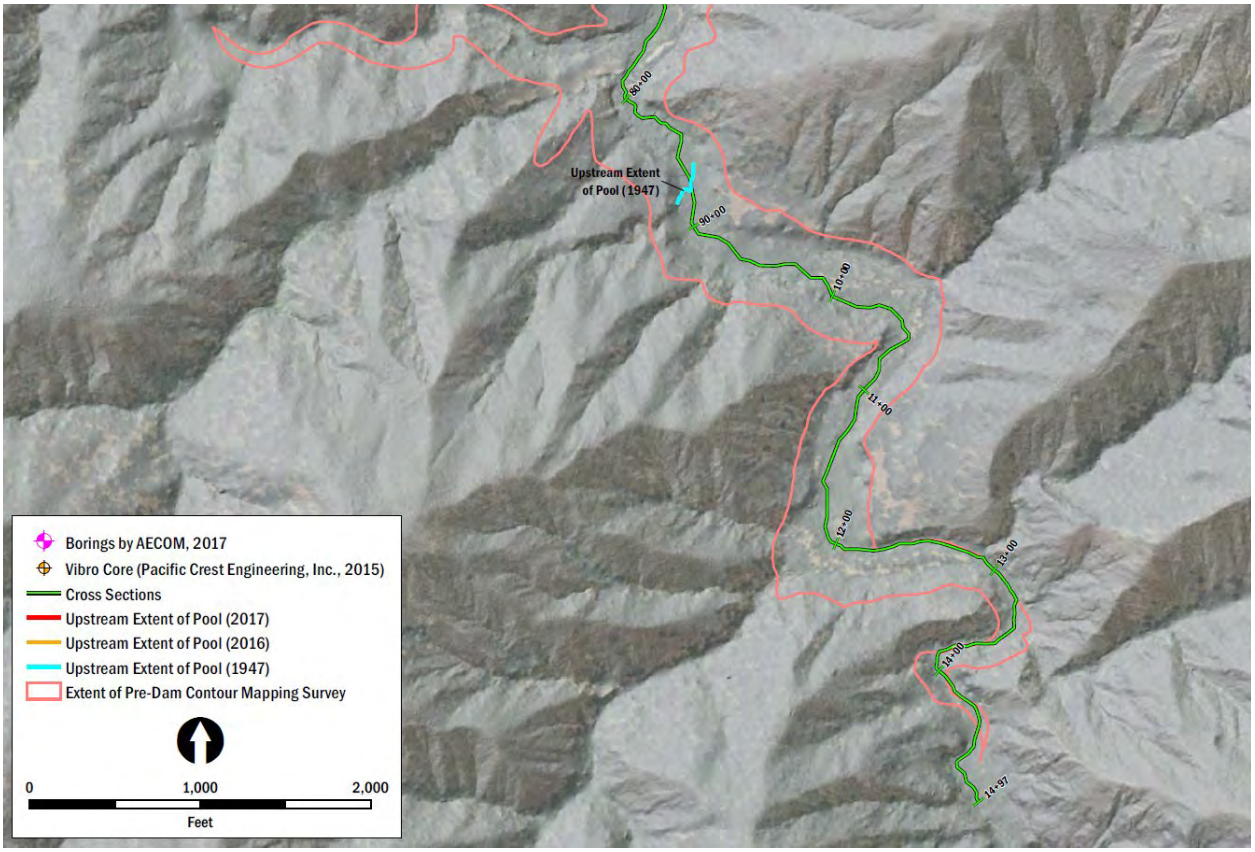


Figure 17 Excerpt of Figure 1 from Sediment Characterization TM, Showing Area of Gravel Deposition (Roughly between Station 90 and Station 12)

Source: AECOM 2018

3.4.5 Summary of Alternative 4 Effects to Steelhead

Alternative 4 would result in the continuation of similar dynamics that occur under existing conditions and under Alternatives 1 and 3 regarding bedload and fish passage conditions. In general, Alternative 4 would provide the highest summer flows capable of providing adequate rearing habitat for both fry and juvenile steelhead downstream of LPD throughout the dry season, in comparison to existing conditions and other dam and reservoir alternatives. The frequent dry back that occurs in the lower 9 miles of the Carmel River is predicted to not occur in normal water years under Alternative 4, due to the increase in summer flow releases from LPD.

Alternative 4 would result in the continued blockage of sediment transport and thus incision of the channel downstream of LPD, resulting in decreased habitat suitability for steelhead, and would continue to limit the quantity and quality of spawning habitat downstream of LPD.

Under Alternative 4, upstream passage facilities at LPD would consist of either a technical fish ladder or a new trap-and-transport facility. Both options would continue to provide upstream passage for adults and support the anadromous population. However, neither option favors juvenile upstream passage; relative to full volitional passage, both options have potential to increase stress and migration delay for migrating steelhead.

Downstream passage facilities under Alternative 4 could consist of an FSC or a modification of the existing spillway and current FWC system. Both preferred fish passage alternatives would result in nonvolitional fish passage, would continue to subject downstream-migrating juveniles to mortality in LPR, and may favor resident and adfluvial over anadromous life histories. Although these options would be an improvement over existing conditions, complete volitional passage (i.e., dam removal) would provide safer migration.

Overall, Alternative 4 would provide the greatest benefits to rearing steelhead downstream of LPD in the summer months when compared to existing conditions and other dam and reservoir alternatives.

3.5 Sediment Management Options

The following section includes an analysis of the effects of sediment management options that could be incorporated into the alternatives described above. A sediment management program could be relevant to all alternatives and would involve activities that could result in either maintaining the existing storage of LPR, increasing the storage capacity over time, or removing fine sediment before dam removal.

3.5.1 Periodic Sediment Removal to Offsite Disposal Site (SM-1)

SM-1 would involve the excavation of a portion of the upstream half of LPR and disposal of dredged material at an offsite disposal site. Depending on the volume of sediment removed, SM-1 would maintain reservoir capacity or could recover some lost reservoir capacity. A detailed description of the location of sediment removal, disposal sites, and timing of sediment removal is provided in Section 3.1 of the Los Padres Alternatives Study in the Draft Alternatives Descriptions TM (AECOM 2017b).

Bedload Sediment Transport

SM-1 would result in no change to the sediment regime over existing conditions, and the effects of bedload would be similar to those evaluated under Alternative 1 in Section 3.1.1.

Water Availability

Depending on the amount of sediment removed from LPR, SM-1 could result in recovery of former reservoir storage, which would allow for an increase in summer flow releases; or maintenance of storage capacities similar to those under existing conditions. If SM-1 results in large quantities of sediment being removed from LPR, the effects of water availability would be similar to those evaluated under Alternative 3 in Section 3.3.2; if smaller amounts of sediment are removed from LPR, effects would be similar to those described under Alternative 1 in Section 3.1.1.

Fish Passage

Fish passage facilities and conditions under SM-1 would generally be the same as those under Alternatives 1, 3, and 4, and are described in Section 3.1.4. Sediment removal has the potential to result in modified topography and bathymetry in the transition between the Carmel River and the upstream portion of LPR, especially immediately following excavation and prior to when streamflow, scour, and deposition have a chance to shape that transitional reach. Sediment removal may need to be designed and managed to accommodate fish passage between LPR and the upstream Carmel River during periods of steelhead migration, so that the sediment management program does not further impede movement of steelhead between the reaches of the Carmel River that are separated by LPD. This effect may also depend on the stage of the reservoir during migration relative to the location of sediment removal, something that may warrant consideration during alternatives development.

Summary of SM-1 Effects to Steelhead

Sediment Management Option 1 (SM-1) would result in no change to existing conditions in the Carmel River downstream of LPD. The effects of SM-1 on steelhead are similar to those discussed in Section 3.1.5. Sediment removal would need to be designed and managed to accommodate fish passage between LPR and the upstream Carmel River.

3.5.2 Periodic Sediment Removal and Placement Downstream (SM-2)

SM-2 (Periodic Sediment Removal and Placement Downstream) would involve excavation of a portion of the coarser sediment from the upstream half of the reservoir and hauling for placement in two areas downstream of the dam in the river channel.

Bedload Sediment Transport

SM-2 would provide a means by which coarser sediments (sand, gravel, and cobble), which are currently trapped by the reservoir, could be moved around the dam to maintain steelhead spawning areas and instream habitat downstream of the dam. The addition of coarse sediment would return sediment to starved reaches downstream of LPD and eventually increase coarse sediment supplies farther downstream. Depending on the quantity of excavated sediment that is placed at the sediment reintroduction sites and then mobilized by high flows, the magnitude of effects would vary. Under existing conditions, MPWMD has occasionally placed suitable spawning gravel in the Carmel River downstream of LPD, including 1,500 tons in 2014 and another 1,000 tons in 2019. These newly placed gravels were readily used by spawning adult steelhead the following winters (MPWMD 2019), suggesting that lack of gravel transport currently affects spawning habitat; when gravel augmentation does occur, steelhead readily spawn in the newly placed gravel.

The effects of SM-2 on bedload as it relates to steelhead and steelhead habitat are greatly dependent on the amount of sediment reintroduced downstream of LPD. If gravel augmentation occurs at intervals similar to those under existing conditions, there would be short- and long-term benefits to steelhead spawning habitat, as evidenced by MPWMD's current gravel augmentation program. The amount of gravel augmentation currently conducted by MPWMD benefits spawning habitat but is unlikely to cause significant changes to downstream channel complexity or increase floodplain habitat. However, with the largest amounts of sediment reintroduced, the response of the channel is expected to be similar to that predicted under Alternative 2 (AECOM 2017b) and could include beneficial effects to rearing habitat.

Water Availability

Depending on the amount of sediment removed from LPR, SM-2 could result in increased reservoir storage, which would allow for an increase in summer flow releases. The effects of water availability under SM-1 would be similar to those evaluated under Alternative 3 in Section 3.3.2.

Fish Passage

Fish passage facilities and conditions under SM-2 would be the same as those under Alternatives 1, 3, and 4, and are described in Section 3.1.4. Like SM-1, manual sediment excavation has the potential to result in modified topography and bathymetry in the transition between the Carmel River and the upstream portion of LPR. The sediment excavation would need to be designed and managed to maintain passage between LPR and the upstream reaches of the Carmel River, depending on the stage of the reservoir during migration, and relative to the location of sediment removal.

Summary of SM-2 Effects to Steelhead

SM-2 would result in benefits to steelhead spawning habitat downstream of LPD through the reintroduction of coarse sediment downstream of LPD. Under existing conditions, gravel augmentation conducted by MPWMD has been shown to be an effective method of increasing the amount of available spawning habitat for steelhead in the Carmel River; however, sediment supply would continue to be limited, relative to Alternative 2.

3.5.3 Sluicing Tunnel (SM-3)

SM-3 would involve the installation of a sluicing tunnel through either the right or left abutment that would be used to flush sediment from the reservoir during wet water years. A typical sluicing operation can be managed either to flush accumulated reservoir sediment (flushing); or to simply pass high sediment-concentrated flow through the reservoir (sluicing), which is typically used to prevent sediment accumulation. A sluicing condition would typically release sediment concentrations similar to those entering the reservoir from the upstream watershed; a flushing condition would release the background concentration as well as additional accumulated sediment, resulting in significantly higher sediment concentrations. Flushing flows would be timed to coincide with high flows that are already carrying significant sediment loads.

SM-3 would likely be paired with dam and reservoir alternatives, either as a means to remove fine sediment and expose the upstream dam toe for the purposes of dam removal (Alternative 2), or to remove fine sediment (and potentially bedload) to restore (Alternative 3) or increase (Alternative 4) reservoir storage capacity.

Fine Sediment Transport

SM-3 would be used to flush accumulated fine sediment (silt, organic matter, and fine sand) during high-flow events. During the initial sluicing events, the majority of sluiced sediment would be fine sediment from the lower reservoir. The increased fine sediment is expected to have little effect on the channel thalweg elevation downstream because fine sediment tends primarily to stay suspended throughout the river to the ocean. However, short-term impacts related to increased suspended sediments include the reduced ability of steelhead to encounter prey, and injury or mortality during periods of increased suspended sediment concentrations. Additionally, as transported sand and fine sediment settles on the streambed, it can reduce the survival of incubating eggs and developing alevins in steelhead redds through reduced oxygenation of intergravel flow.

Section 2.2 describes the limited fine sediment analysis, which concluded that the 1,300 mg/L peak concentration resulting from the episodic rating curve represents a typical high-turbidity event contributing to the reservoir from the watershed as background conditions. The 5,800 mg/L peak concentration resulting from the hypothetical discharge of all Zone 1 sediment represents a sediment release condition where a portion of the reservoir sediment leaves the reservoir in flows that are consistently high over several consecutive days. Based on literature review of previous dam removal projects that included sediment flushing, a true flushing event can put orders of magnitude more material in suspension than the estimates above, potentially resulting in peak concentrations greater than 49,000 mg/L. Although the reviewed dam removal data showed high suspended sediment concentrations lasting for 1 to 2 months, those conditions occurred because of continuous access to reservoir sediments resulting from long periods of high flow in the White Salmon and Sandy Rivers; these conditions do not tend to occur on the Carmel River. The duration of high sediment concentrations would be limited by the operation of the sluice gate at LPD, which would restrict high sediment concentration durations to typically around 2 to 5 days, based on the duration of typical flows that fall within a sluicing operational range of 500 to 5,000 cfs. Additional limitations on flushing could be developed to limit the duration or frequency of effects on steelhead, if appropriate.

Based on the large range of expected suspended sediment concentrations and the range of potential durations of increased suspended sediment concentrations, effects to steelhead would range from stressful to lethal. Suspended sediment concentrations would likely be greatest immediately downstream of LPD and would gradually decrease as sediment is diluted through tributary contributions to flow in the mainstem during periods of storm runoff.

As discussed in Section 2.2, using the general predictions of suspended sediment concentration and durations, the results of Newcombe and Jensen (1996) were used to conservatively assess impacts of suspended sediment on steelhead. Due to the flexibility in the management of a sluicing operation, we analyzed the effects of the predicted range of suspended sediment concentrations over the range of durations predicted to occur (2 to 5 days).

If suspended sediment concentrations resulting from sluicing or flushing were to remain at 5,800 mg/L over the course of 3 days, upstream migrating adults are predicted to experience an SEV of 10 during the migratory period (December through April) while active sluicing is occurring (Table 5). An SEV of 10 is associated with lethal and paralethal effects, with 0 to 20 percent mortality. This level of effect is anticipated to result in some mortality and delayed migration timing. If the flushing event were to occur after spawning had occurred, incubating eggs and alevins are predicted to experience an SEV of 13, which is also associated with lethal and paralethal effects, resulting in >60 to 80 percent mortality (Table 5). Fry and juvenile steelhead are predicted to experience an SEV of 10 (Table 5). This level of effect over the course of the sluicing event is anticipated to result in some mortality; increased risks of predation resulting from physiological stress, especially where nonnative piscivorous fish species (e.g., brown trout and striped bass) occur; and a reduction in the foraging ability of juvenile steelhead. If sluicing operations could be controlled to release 5,800 mg/L of sediment over a short duration (<12 hours), impacts to fry, juveniles, and adults would be sublethal. Impacts to the more sensitive incubating eggs would still be lethal.

Table 5 Summary of Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Steelhead in the Carmel River Downstream of LPD during Sluicing Events Producing 5,800 mg/L of Suspended Sediment Concentrations for 3 Days

Life Stage	Total Exposure (hours)	Total CD (mg-hr/L)	SEV	Effects
Adult	72	417,600	10	0 to 20% mortality; increased predation; moderate to severe habitat degradation
Eggs and alevins			13	>60 to 80% mortality
Fry and juveniles			10	0 to 20% mortality; increased predation; moderate to severe habitat degradation

Notes:

CD = product of concentration and duration
LPD = Los Padres Dam
mg-hr/L = milligrams per hour per liter
mg/L = milligrams per liter
SEV = severity of ill effect

In the worst case scenario of a flushing event sending suspended sediment concentrations of up to 49,000 mg/L over the course of several days, steelhead in the Carmel River downstream of LPD would generally experience lethal effects. Upstream migrating adults are predicted to experience an SEV of 11 during the migratory period (December through April) while active flushing is occurring (Table 6). An SEV of 11 is associated with lethal and paralethal effects, with >20 to 40 percent mortality expected. This level of effect is anticipated to result in adult mortality and delayed migration timing. Eggs and alevins are predicted to experience an SEV of 14, which is also associated with lethal and paralethal effects, resulting in >80 to 100 percent mortality (Table 6). This level of mortality is anticipated to severely reduce successful hatching of redds and result in mortality of alevins, severely reducing successful recruitment of steelhead in affected reaches. Fry and juvenile steelhead are predicted to experience an SEV of 11, which would result in >20 to 40 percent mortality (Table 6). This level of effect over the course of the flushing event is anticipated to result in mortality; increased risks of predation, especially where nonnative piscivorous fish species (e.g., brown trout and striped bass) occur; and reduction in the foraging ability of juvenile steelhead, resulting in reduced growth rates. If sluicing operations could be controlled to release 49,000 mg/L of sediment over a short duration (<2 hours), impacts to fry, juveniles, and adults would be sublethal. Impacts to the more sensitive incubating eggs would still be lethal.

Table 6 Summary of Predicted Newcombe and Jensen Severity Index and Anticipated Effects on Steelhead in the Carmel River Downstream of LPD during Sluicing Events Producing 49,000 mg/L of Suspended Sediment Concentrations for 3 Days

Life Stage	Total Exposure (hours)	Total CD (mg-hr/L)	SEV	Effects
Adult	72	3,528,000	11	>20 to 40% mortality
Eggs and alevins			14	>80 to 100% mortality
Fry and juveniles			11	>20 to 40% mortality

Notes:

CD = product of concentration and duration
LPD = Los Padres Dam
mg-hr/L = milligrams per hour per liter
mg/L = milligrams per liter
SEV = severity of ill effect

As discussed in Section 2.2, Suspended Sediment, the analysis conducted for suspended sediment concentrations was limited in its ability to provide specific magnitudes and durations of suspended sediment concentrations. Based on the outputs of this analysis, flushing could result in increased mortality of steelhead downstream of LPD. Although flushing events are anticipated to occur concurrently with winter storm events, they still could result in substantial effects to all life stages of steelhead—especially eggs and alevins, which would reduce the successful recruitment of steelhead in years that flushing occurs. However, if sluicing operations were conducted for short (<24 hours) durations, coincident with winter high flows when all tributaries are typically accessible, steelhead may avoid the peak in concentrations by using refugia habitat in tributaries, side channels, or off-channel habitat. Several tributaries (e.g., Cachagua, Pine, San Clemente, Tularcitos, and Garzas Creeks) downstream of San Clemente Dam would presumably provide refugia from flushed sediment (Figure 16). Approximately 43 percent of the suitable steelhead rearing habitat in the Carmel River Watershed is estimated to be either in tributaries or upstream of LPD (Table 1). Therefore, a substantial portion of the rearing population would not be in the mainstem Carmel River during sediment release and would therefore be unaffected by sluicing operations. The portion of the population that would avoid all impacts of sluicing would presumably recolonize the mainstem and support a strong recovery of the population, especially if sluicing operations were conducted infrequently (e.g., every 5 years or more).

Bedload Sediment Transport

Depending on how sluicing and flushing are managed, the amount of coarse sediment moving downstream would vary. If the intent is to restore reservoir capacity, the sluicing could be managed to only mobilize the fine sediment and maintain the coarse sediment in place, thus preventing it from moving farther into the reservoir and displacing reservoir capacity. SM-3 is not expected to improve downstream aquatic habitat, and effects of SM-3 on bedload would be similar to those evaluated under Alternative 1 in Section 3.1.1.

Water Availability

Depending on the amount of sediment removed from LPR, SM-3 could result in increased reservoir storage, which would allow for an increase in summer flow releases. The effects of water availability under SM-3 would be similar to those evaluated under Alternative 3 in Section 3.3.2.

Fish Passage

Fish passage facilities and conditions under SM-3 would be like those under Alternatives 1, 3, and 4, and are described in Section 3.1.4. Flushing accumulated fine sediment from the lower reservoir could affect the topography and bathymetry in the transition between Zone 2 and Zone 3 sediments (see Revised Sediment Characterization TM [AECOM 2018] for the extent of sediment zones) in LPR. However, this effect would be deeper in the reservoir and, depending on the stage of the reservoir during periods of steelhead migration, may have less potential to affect fish passage than SM-1 and SM-2. Additionally, the bathymetry in this case would be shaped by the work done by fluvial processes (e.g., scour) as opposed to mechanical excavation, so would likely result in smoother transitions.

During the operation of the sluicing tunnel, steelhead in LPR have the potential to become entrained in the tunnel and transported downstream of LPD. If entrained, adult steelhead migrating through the reservoir would fall back downstream; juveniles migrating or rearing in the reservoir could be transported downstream; and brown trout rearing in the reservoir could also be transported downstream. The overall effect of potential entrainment would depend on the seasonal timing, frequency, and duration of operation of the tunnel, as well as the risk of injury or mortality for those fish entrained.

Summary of SM-3 Effects to Steelhead

SM-3 would result in effects to water availability, water temperature, and fish passage similar to those described under Alternative 1 in Sections 3.1.2, 3.1.3, and 3.1.4.

Depending on how the flushing operation is managed under SM-3, steelhead in the Carmel River downstream of LPD could experience significant levels of mortality resulting from increased suspended sediment concentrations. Generally, under the predicted range of durations and concentrations, all life stages of steelhead would experience paralethal and lethal effects as a result of increased suspended sediment concentrations. This level of effect is expected to have a substantial effect on the steelhead population in the Carmel River, and flushing operations would need to be managed to reduce the risks.

Due to the severity of effects to steelhead predicted by the limited fine sediment transport analysis presented in Chapter 2, if SM-3 is selected for further development, sediment transport modeling of the sluicing and flushing operations is recommended. This will increase confidence in the estimated range of sediment concentration magnitudes and durations, and the potential changes to these over a series of operations and storm events, because it is possible that suspended sediment concentrations could be much higher.

3.6 Conclusion

The South-Central California Coast Steelhead Recovery Plan (NMFS 2013) emphasizes the following framework as a necessary component of the recovery of the S-CCC steelhead population: “solutions that emphasize resilience in the face of projected climate change to ensure a sustainable future for both human communities and steelhead.” In general, the alternatives evaluated in this report benefit steelhead in the Carmel River by either restoring natural processes to the river or through the continued augmentation of summer flows. The benefits of a managed system that includes features such as managed fish passage (Alternatives 1, 3, and 4), movement of course sediment from upstream to downstream of LPD (SM-1 and SM-2), and maintenance of reservoir capacity to augment downstream flows depend on managers maintaining the will and funding to continue operation of these features year after year, where funding may be contingent on the willingness of the public to support such programs. In that sense, and because dam removal is essentially permanent, the benefits associated with Alternative 2, as well as the reduction in summer flow downstream of LPD, are most likely to endure following implementation of any action at LPD and LPR.

The key response variables evaluated for each dam and reservoir alternative and their potential effects on steelhead in the Carmel River watershed are summarized in Table 7. In general, Alternatives 1, 3, and 4 would retain LPD and allow for the continued release of water downstream of LPD in the summer months, resulting in increased wetted habitat during the dry season when compared to Alternative 2. Although alternatives that maintain LPD provide increased wetted habitat in the summer, the presence of LPR would continue to increase water temperatures in the Carmel River. Furthermore, LPD would continue to prevent access for juvenile steelhead to cold-water habitat upstream of LPR, which would otherwise provide thermal and drought refugia. These alternatives would also continue to prevent the transport of coarse sediment from upstream of LPD, which would continue to affect the quantity and quality of steelhead spawning and rearing habitat downstream of LPD, primarily in Reach 1. However, inclusion of SM-2 could help mitigate this effect.

If Alternatives 1, 3, or 4 are paired with an effective and well-executed sediment management option, in which a large supply of coarse-sized gravel is introduced into the Carmel River downstream of LPD (SM-2), there would be enhanced rearing habitat and spawning habitat. Through the sediment management program, habitat complexity downstream of LPD would increase, and the introduction of coarse-sized gravel would increase spawning habitat in the Carmel River. If the gravel augmentation were increased in magnitude to a full sediment management program, there could be tangible benefits to steelhead spawner abundance and instream habitat.

Table 7 Summary of Dam and Reservoir Alternatives Effects on Steelhead

	Sediment Transport	Water Availability	Water Temperature	Fish Passage
Alternative 1 (LPD Remains, No Sediment Management, CDO)	Lack of sediment transport from upstream of LPD would result in decreased spawning habitat and decreased habitat complexity	Water availability similar to that under existing conditions, gradually reducing as LPR capacity decreases (excepting inclusion of SM-1, SM-2, or SM-3)	Suboptimal water temperature regime in the summer months and the continued blockage of thermal refugia upstream of LPR	• Adult and smolt passage facilities • No upstream passage for juvenile steelhead • Migration through reservoir
Alternative 2 (Dam Removal)	Restore natural sediment transport, resulting in increased habitat complexity and increased spawning habitat downstream of LPD	Decreased water availability during summer months, resulting in decreased wetted habitat relative to existing conditions	Restore a natural thermal regime to the Carmel River downstream of LPD, providing access to thermal refugia habitat upstream of LPR	• Fully volitional upstream and downstream fish passage for all steelhead life stages • No reservoir migration
Alternative 3 (Restore Reservoir Capacity)	Lack of sediment transport from upstream of LPD (excepting inclusion of SM-2) would result in decreased spawning habitat and decreased habitat complexity	Increased water availability to augment summer flows, resulting in more wetted habitat in the summer months when compared to Alternatives 1 and 2	Suboptimal water temperatures in the summer months and the continued blockage of thermal refugia upstream of LPR	• Adult and smolt passage facilities • No upstream passage for juvenile steelhead • Migration through reservoir
Alternative 4 (Storage Expansion)	Lack of sediment transport from upstream of LPD (excepting inclusion of SM-2), resulting in decreased spawning habitat and decreased habitat complexity	Increased water availability in the summer, which would result in more wetted habitat and increased connectivity of the Carmel River downstream of LPD relative to all other dam and reservoir alternatives	Suboptimal water temperatures in the summer months and the continued blockage of thermal refugia upstream of LPR	• Adult and smolt passage facilities • No upstream passage for juvenile steelhead • Migration through reservoir

Notes:

CDO = cease and desist order
LPD = Los Padres Dam
LPR = Los Padres Reservoir

In other projects where sediment transport processes and volitional fish passage were restored, steelhead recolonization occurred rapidly. Examples include the restoration of fish passage following fish ladder installation at Landsburg Dam on the Cedar River, Washington (Kiffney et al. 2009), and following removal of Condit Dam on the White Salmon River, Washington (Allen et al. 2016). Steelhead recolonization of habitat upstream of Condit Dam was notable, with steelhead spawning observed in upper basin tributaries within 5 years of dam removal. However, fish passage (existing facilities) and limited sediment transport (gravel augmentation mentioned in Section 3.1.1) occur now at LPD and will occur to some degree under all alternatives evaluated. Therefore, some differences among alternatives are nuanced, and the steelhead population response may not be as dramatic or immediate as restoring fish passage at a dam where there was none previously. Differences among alternatives are most pronounced when comparing the benefits to the steelhead population of additional wetted habitat in the lower Carmel River under Alternatives 1, 2, and 4 with the impacts on downstream migrating juvenile steelhead from the continued existence of LPR and from challenges in downstream migration past the dam. Development of a lifecycle population dynamics model would allow for a more quantitative evaluation of tradeoffs, including the important tradeoff between augmented summer rearing flows in the lower river and unimpeded passage at LPD and LPR, as well as other, more subtle differences among alternatives.

Improvements to the existing fish passage facilities at LPD are a critical component of Alternatives 1, 3, and 4. Although adult fish would likely continue to use the upper watershed to spawn under these alternatives, reservoir dynamics and downstream passage facilities in LPR are likely to continue to limit the successful downstream passage of smolts from upstream of LPR, which could limit the anadromous production of steelhead in the Carmel River. If a dam and reservoir alternative is selected that retains LPD, one of the preferred upstream and downstream fish passage alternatives described in the Fish Passage Feasibility Report (HDR et al. 2021) would be adapted to that alternative for a complete Los Padres project alternative.

Alternative 2 would restore natural processes to the Carmel River, resulting in an uninterrupted thermal regime, unimpeded passage to both the upper and lower watershed for migrating steelhead, and a natural sediment transport supply to the Carmel River downstream of LPD. By removing LPD, wetted habitat downstream of LPD during summer months is predicted to be more limited than with other dam and reservoir alternatives. However, steelhead rearing in the Carmel River would have access to habitat upstream of LPR, which currently provides thermal and drought refugia habitat.

Sediment management option SM-1 is unlikely to have any effect on steelhead or steelhead habitat in the Carmel River or LPR, because the dredged sediment would be placed outside the river. Sediment management option SM-2 could result in benefits to steelhead spawning habitat downstream, although the magnitude of the benefit depends on the quantity of coarse sediment supplied to reaches downstream of LPD. Based on the current sediment concentration and duration projections for a flushing operation intended to clear LPR of accumulated sediment under SM-3, effects to steelhead could be significant and have the potential to cause substantial injury or mortality in the mainstem Carmel River downstream of LPD. In addition to having detrimental effects to all life stages of steelhead in the Carmel River downstream of LPD, the release of fine sediment could temporarily decrease the amount of available spawning habitat and decrease benthic macroinvertebrate production downstream of LPD. The general assessment of suspended sediment release under SM-3 and conservative analysis of the effects on steelhead presented in this TM both warrant a second look if the preferred dam and reservoir alternative includes SM-3. For example, managing sluicing to reduce frequency and duration of release, considering refugia from suspended sediment available to Carmel River steelhead (e.g., tributary mouths, protected backwaters, and springs), and considering the relative contribution to the population from tributaries or upstream of LPD that would be unaffected by sediment flushing, could all refine the potential efficacy and effects on steelhead of this sediment management option.

The following additional uncertainties remain and may warrant further investigation prior to selecting a dam and reservoir alternative:

- Life history of juvenile steelhead upstream of LPD, including downstream migration timing, reservoir rearing, residualization, survival, and behavior
- Adult migration delay downstream of LPD
- Potential for and effects of entrainment in sluicing tunnel
- Suspended sediment concentrations and durations resulting from sluicing operations (for ongoing management or flushing prior to dam removal)
- Temperature effects of alternatives and ability to manage downstream temperature with releases from LPR
- Relative population productivity dynamics (including available spawning and rearing habitat) of Carmel River downstream of LPD, Carmel River upstream of LPD, and in tributaries of the Carmel River downstream of LPD

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Attachment A
CRBHM Presentation, November 3, 2020

Carmel River Basin Hydrologic Model (Calibrated Historic)

Team:
Jonathan Lear, Thomas Christensen, Mike Hutnak
Richard Niswonger (USGS) and Justin Huntington

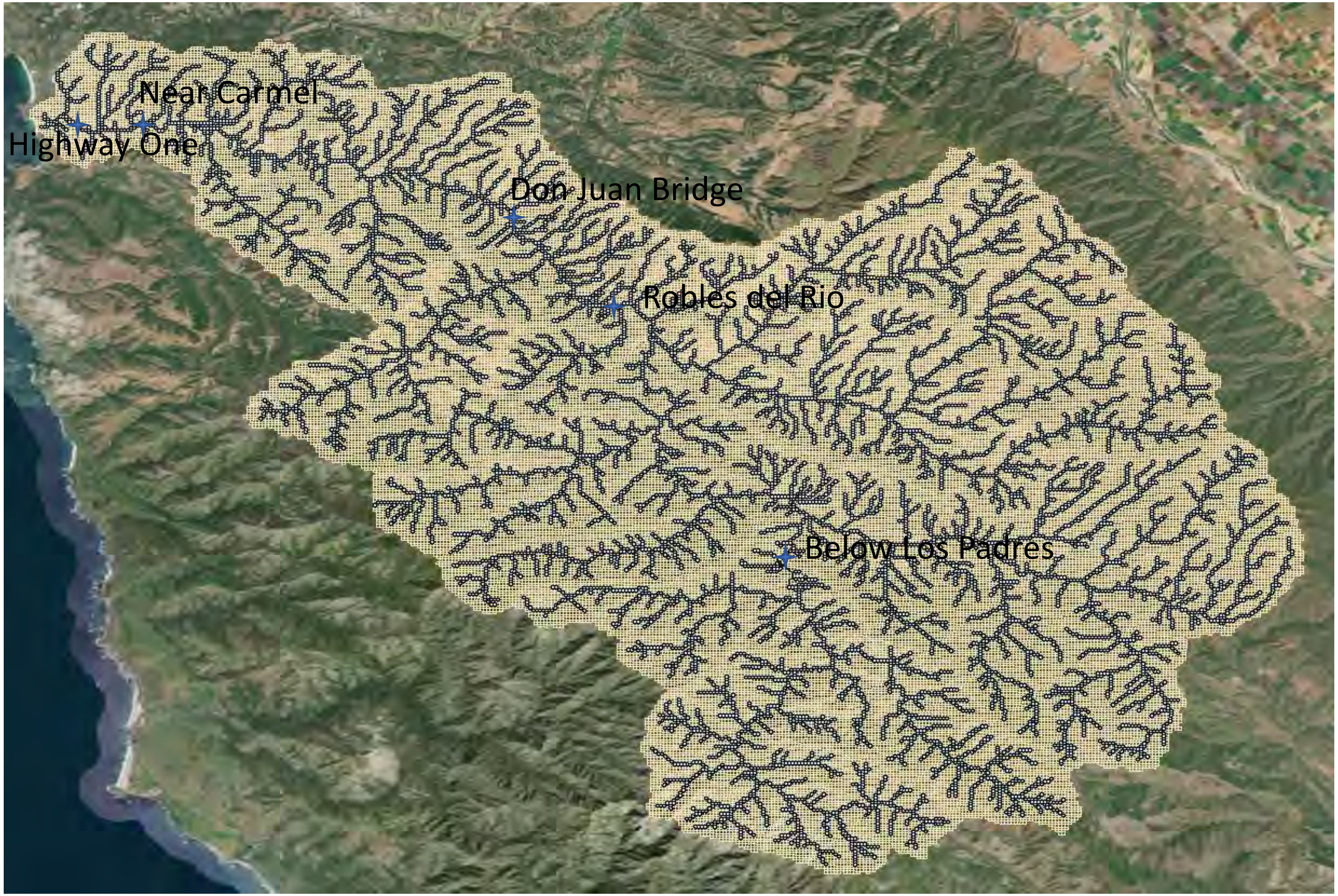
06/23/2020 Simulation

Presentation Date
11/3/2020

Overview

- Review of the Carmel River Basin Hydrologic Model (CRBHM)
  - Model Grid
  - Data Sets
  - Sources of Uncertainty
- General Comments from NOAA on CRBHM July 10, 2020 Presentation
- Root mean square error for different stream gages
- Nash-Sutcliffe Efficiency plots for different stream gages
- Simulated vs residual plots for streamflow at different stream gages
- Groundwater root mean square error by well tier and residual plots
- Example hydrographs from the calibrated historic CRBHM
- Current Scenarios in the Los Padres Removal Study
- Some example model results with and without Los Padres Reservoir
- Model efficiency conclusions

GSFLOW
CRBHM Grid, Flow Network and Mainstem Stream Gages



Carmel River Main Stem Through Rancho Canada

Data Sets

- Modeling period – WY 1992 to WY 2015
- Data sets –
  - Rainfall – San Clemente Rainfall (Daily)
  - Temperature – Carmel Valley Village COOP and Hastings COOP Daily High and Low
  - Evapotranspiration – Vegetation
  - Streamflow – USGS and MPWMD stream gage records
  - Pumping – Cal-Am Muni, Private Metered, and Private Water Systems
  - Groundwater Levels – MPWMD and Cal-Am Networks
  - Geology – USGS Geology
  - Soils – State soils database
  - Channel Geometry – FEMA (2009)

Sources of Uncertainty in Hydrologic Modeling of the Carmel River Basin

Limitations include uncertainties in the spatial variability of precipitation interpolated over the Carmel River watershed because of the limited number of climate stations with available records of daily precipitation and temperature over the model time domain. In addition, the Carmel River is a flashy system.

Data limitation of the model is the uncertainty in the estimates of temporal distribution of rural pumpage (defined as a combination of agricultural and domestic pumpage). In addition, uncertainty in Cal-Am pumping (well on/off log sheets)

Removal of San Clemente Reservoir from CRBHM. Effects of San Clemente Reservoir and changes in reservoir storage due to siltation and effects on flood waves and drawdown due to seismic concerns are not being simulated.

Changes in Riparian Corridor. Riparian corridor was restored over the time of the model simulation. Extent of riparian vegetation was digitized from air photos from 2008 where the extent of the corridor remains today.

Lack of operational records to recreate historic Los Padres operations. Outlet works of reservoir have changed and daily records did not capture complete operations of all outlet ports in the 1990s.

Effects of Lagoon backwater on HWY1 gage prior to moving the gage in 2015.

Complex subsurface hydrogeologic conditions.

Variability in irrigation efficiencies and recharge from land use.

General Comments from NOAA addressed in this Presentation

- Please provide Root Mean Squared Error (RMSE) and Nash Sutcliffe Efficiency (NSE) for streamflow at mainstem stations
- Provide plots of residuals versus simulated streamflow
- Provide scatter plots for simulated groundwater elevations as well as RMSE for these wells
- Provide plots of residuals versus simulated groundwater levels
- Concerned that the model overestimates lower flows

Root Mean Square Error for Different Stream Gages on the Carmel River (cfs)

Gage Site		RMSE Daily Entire Sim.	RMSE Daily lowflow (April -Oct)	RMSE Daily lowflow (May-Sept) under 50 cfs
Highway One		218	58	10.0
Near Carmel		203	59	11.3
Don Juan Bridge (Garland)		162	49	11.0
Robles del Rio		150	44	11.9
Below Los Padres		75	35	8.5

Nash-Sutcliffe Efficiency values for goodness-of-fit evaluations (how well does your model predict observed values)

• Very Good	NSE > 0.90
• Good	NSE = 0.80-0.90
• Acceptable	NSE = 0.65-0.80
• Unsatisfactory	NSE = less than 0.65

- Source = Performance evaluation of hydrological models: Statistical significance for reducing subjectivity in goodness-of-fit assessments

  Axel Ritter, Rafael Muñoz-Carpena

Nash-Sutcliffe Efficiency values for goodness-of-fit evaluations for Carmel River Stream Gages

Gage Location	NSE Daily Entire Sim.	NSE Daily low flow*	NSE Weekly Entire Sim.	NSE Weekly low flow*	Rating Daily Low Flow
Highway One Gage	0.54	0.74	0.66	0.84	Acceptable
Near Carmel Gage	0.56	0.75	0.74	0.87	Acceptable
Don Jaun Bridge Gage	0.7	0.78	0.82	0.83	Acceptable
Robles del Rio Gage	0.72	0.78	0.86	0.86	Acceptable
Below Los Padres Gage	0.56	0.72	0.73	0.73	Acceptable

*low flow recession April-October

Rating Key

Very Good NSE > 0.90

Good NSE = 0.80-0.90

Acceptable NSE = 0.65-0.80

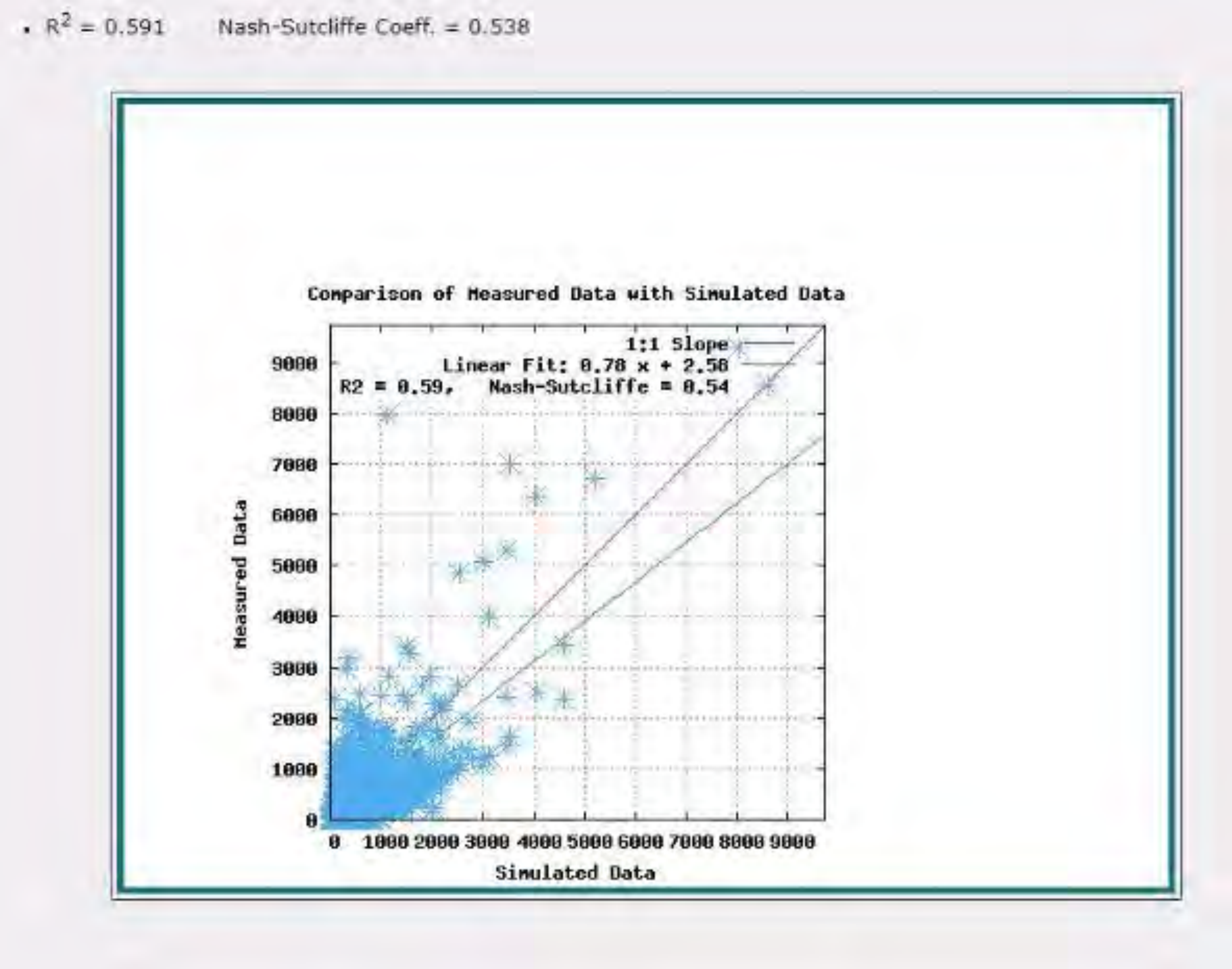
Unsatisfactory NSE = less than 0.65

From Axel Ritter and Rafael Munoz-Carpena

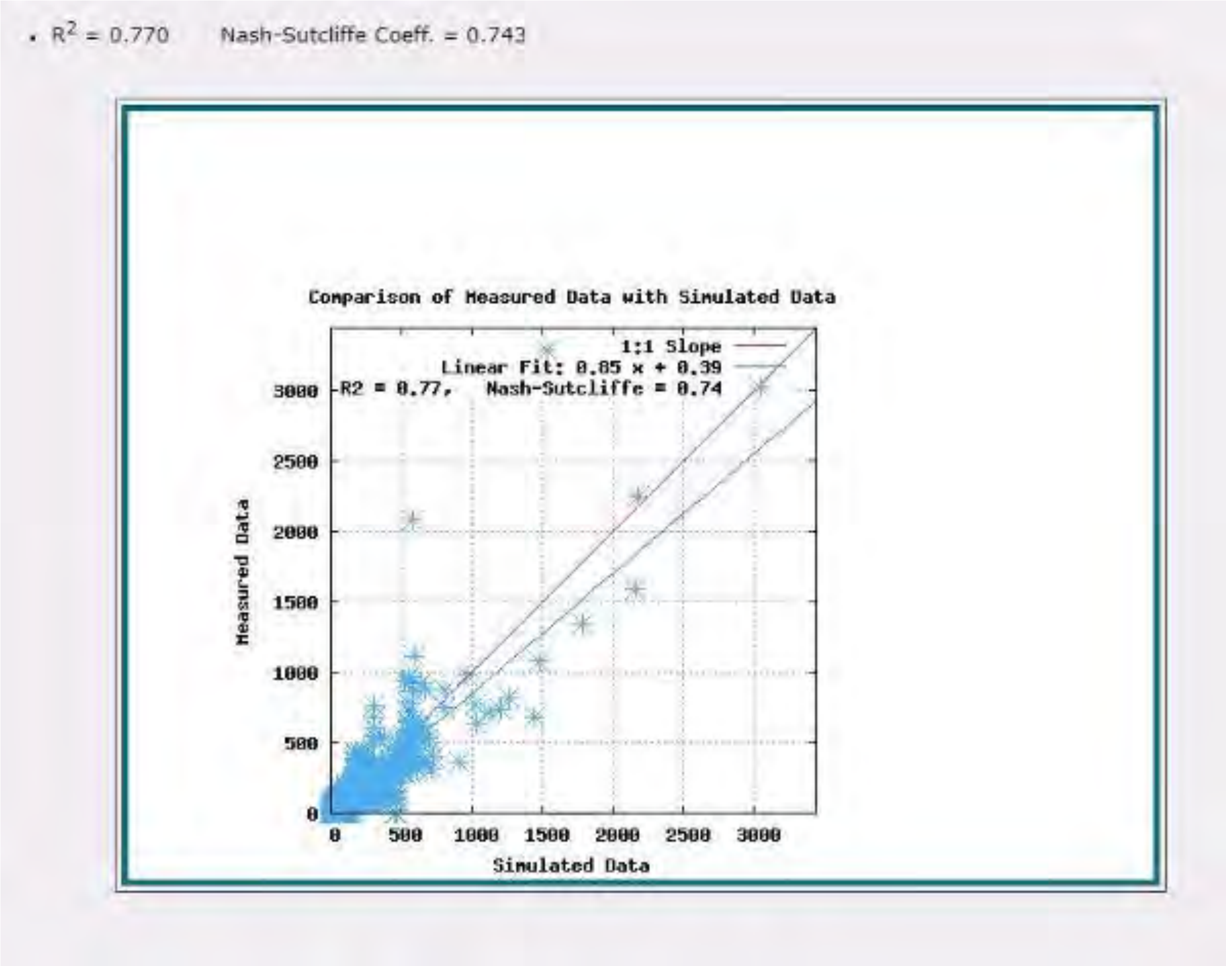
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Highway One Gage

NSE Daily Entire Simulation



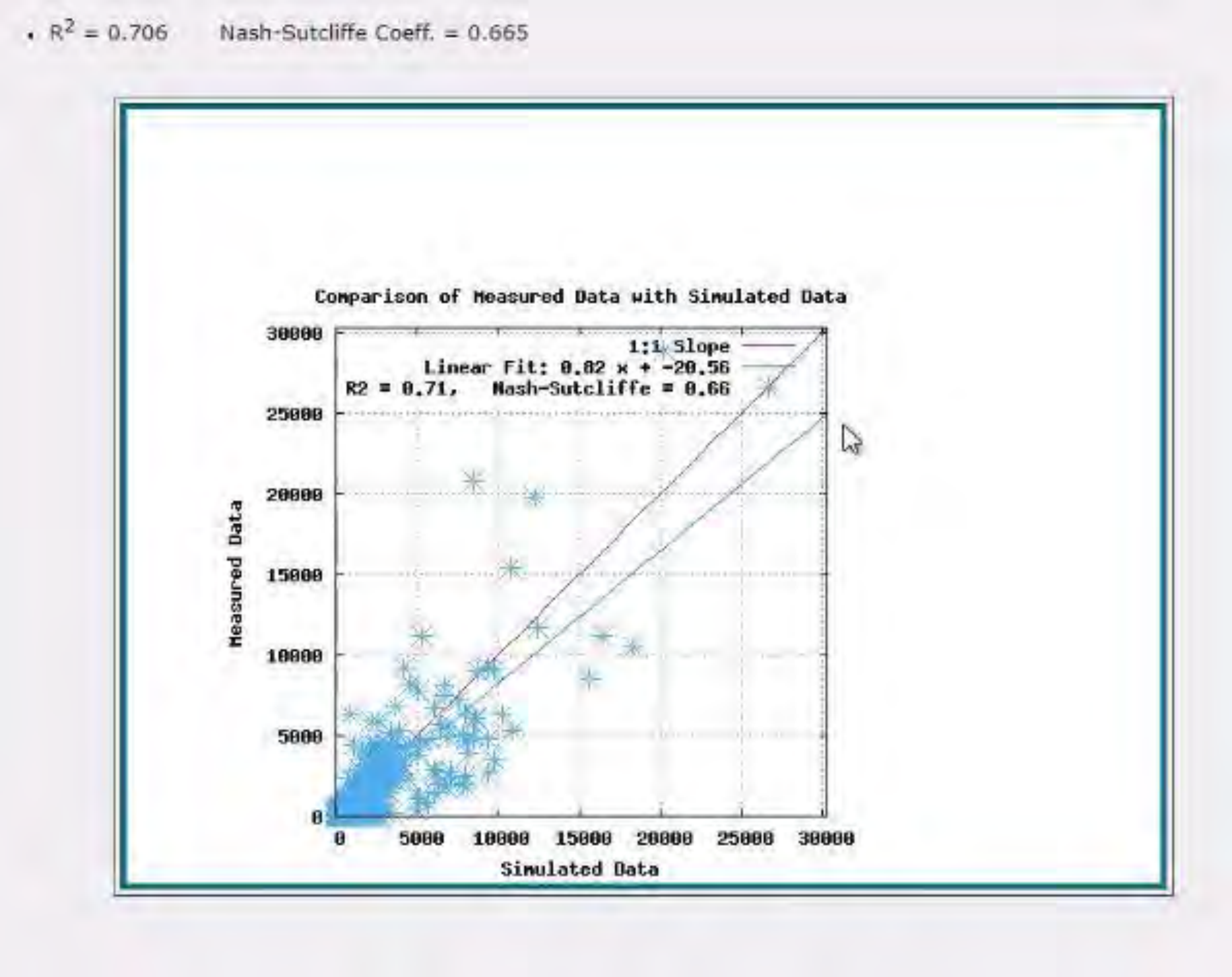
NSE Daily low flows (Apr.-Oct)



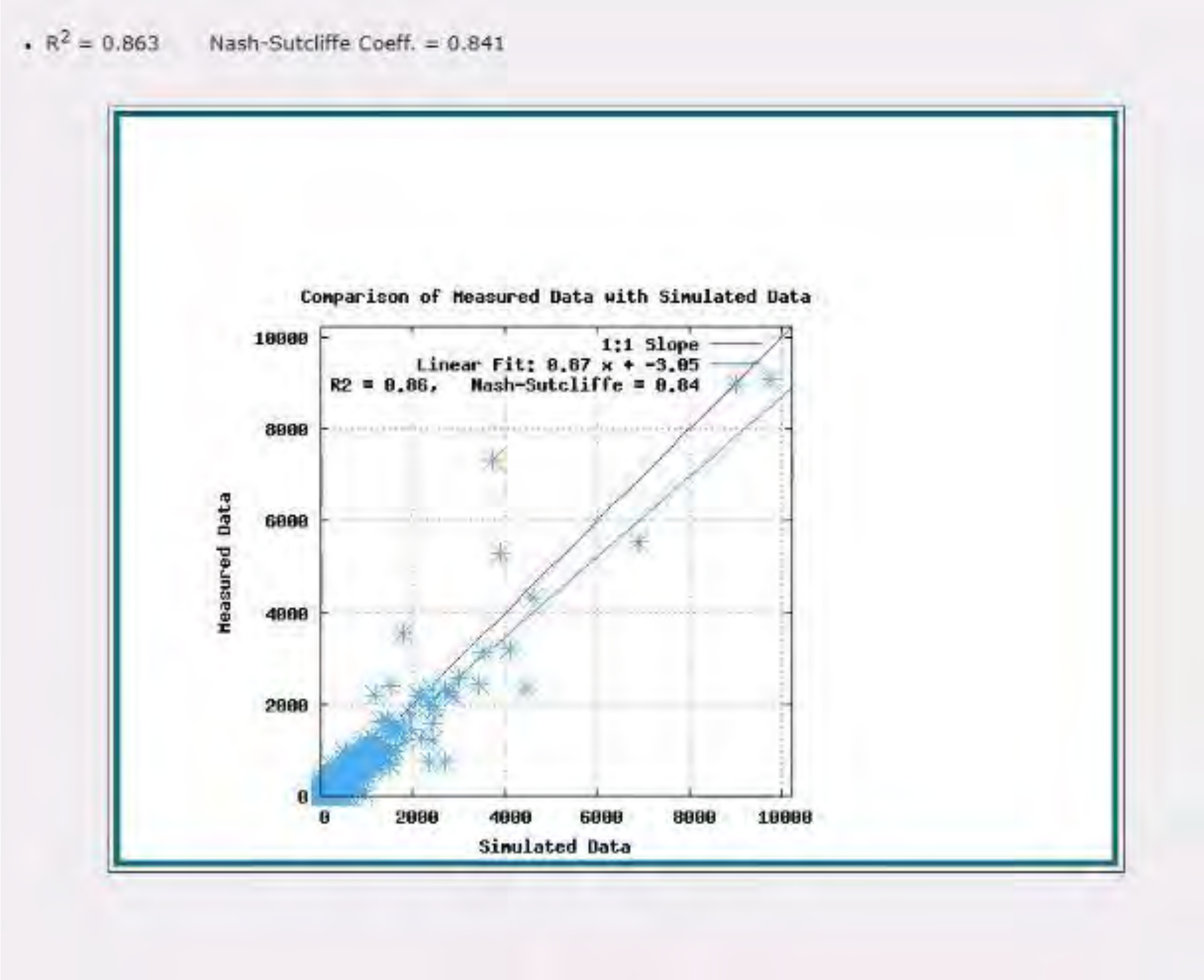
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Highway One Gage

NSE Weekly Entire Simulation



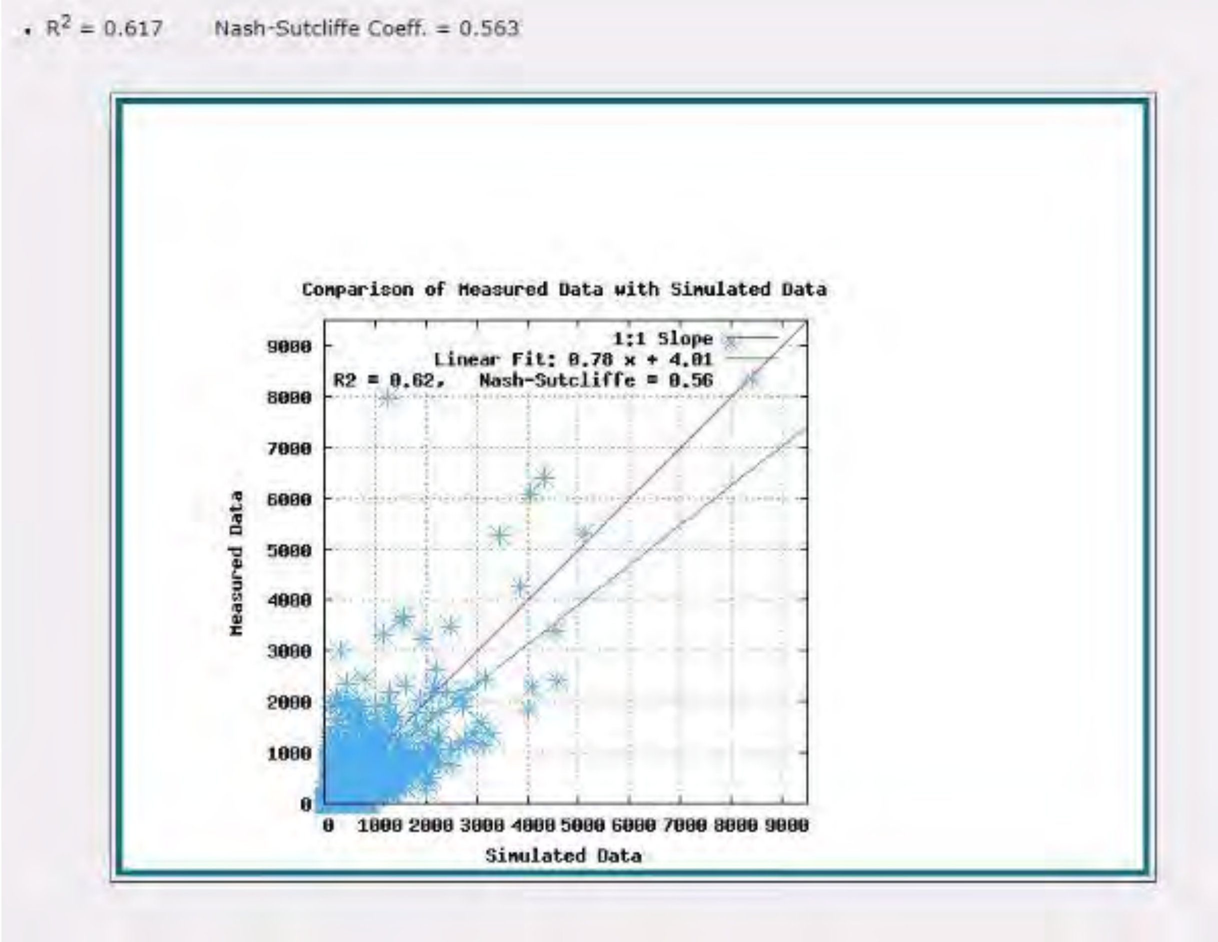
NSE Weekly low flows (Apr.-Oct)



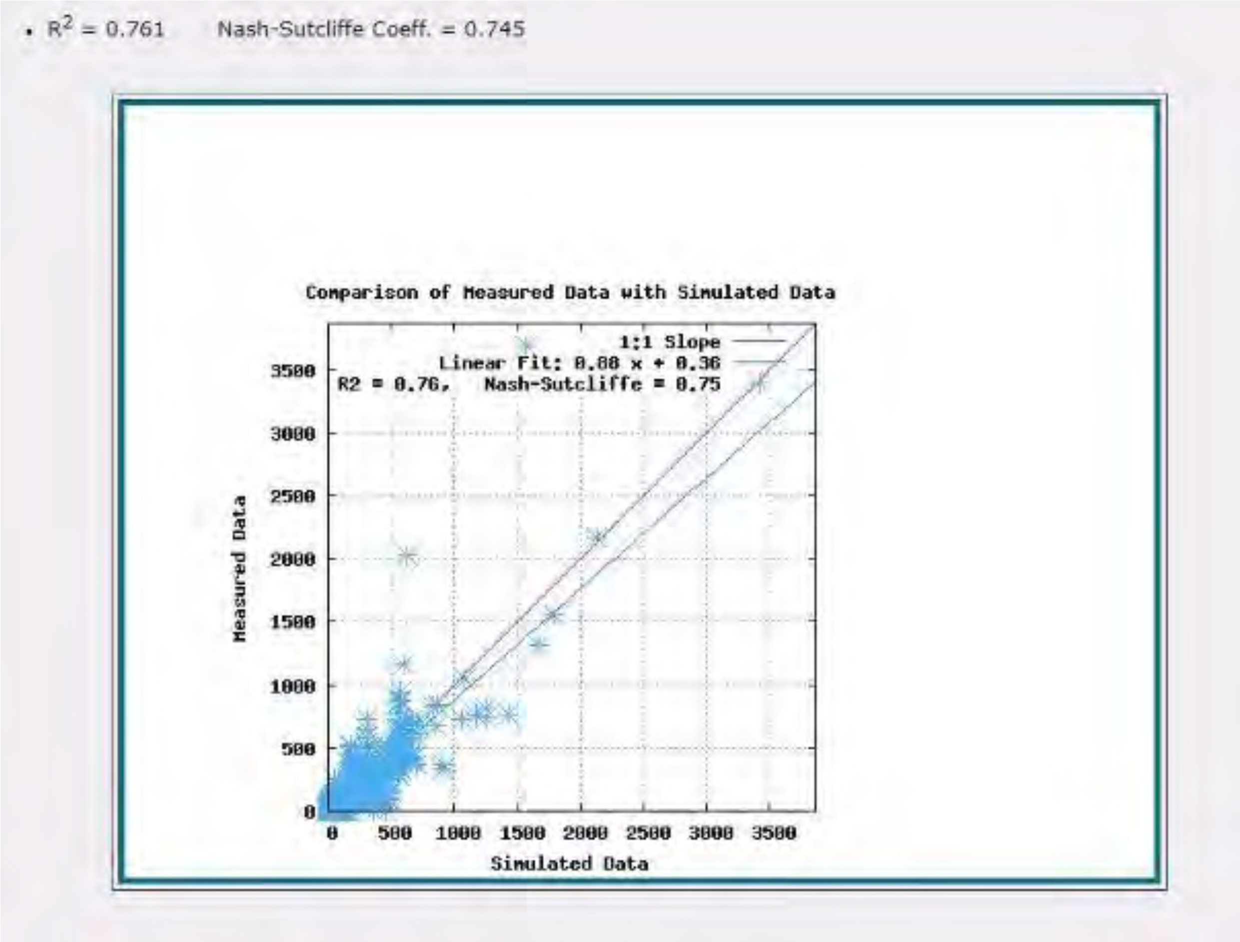
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Near Carmel

NSE Daily Entire Simulation



NSE Daily low flows (Apr.-Oct)



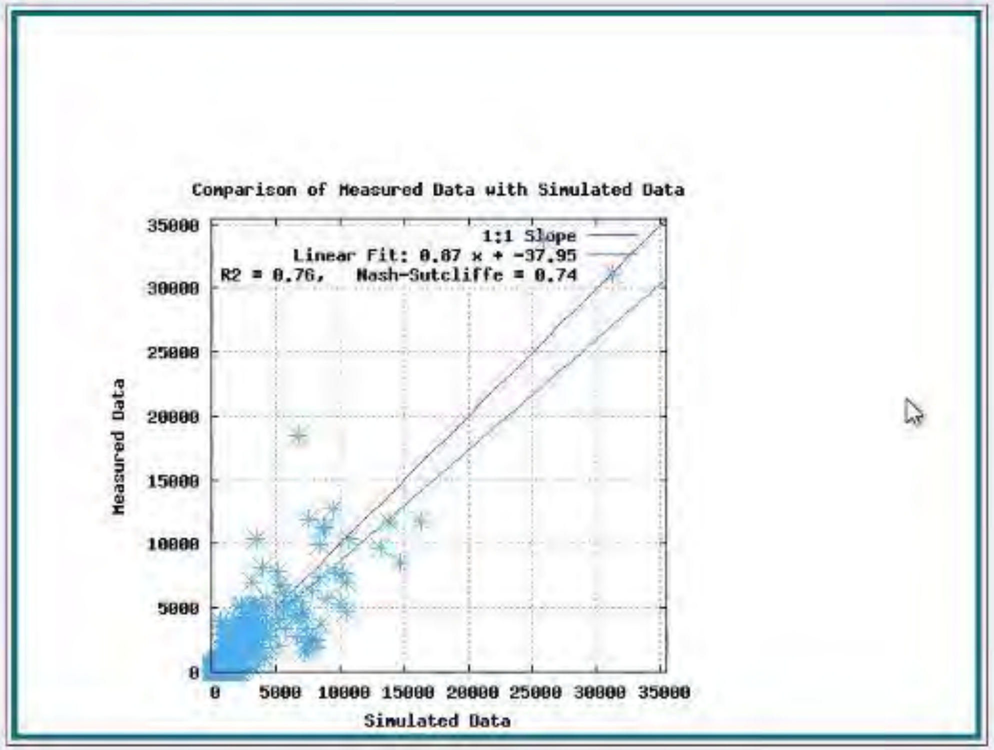
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Near Carmel

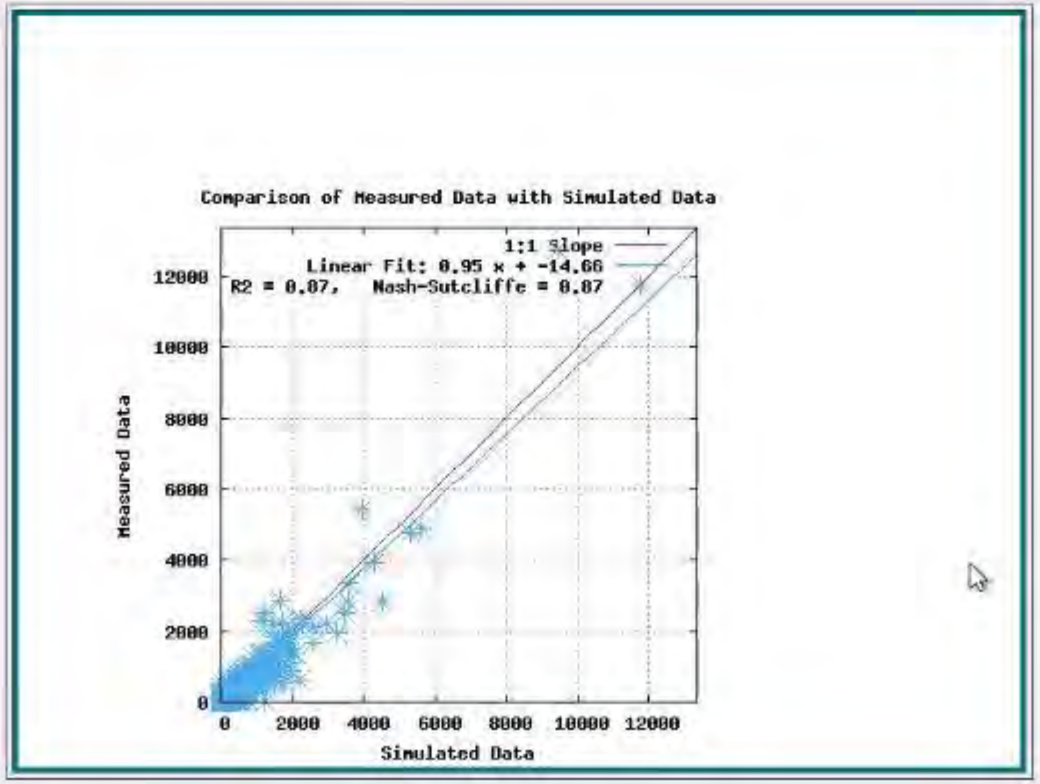
NSE Weekly Entire Simulation

NSE Weekly low flows (Apr.-Oct)

- $R^2 = 0.765$ Nash-Sutcliffe Coeff. = 0.741



- $R^2 = 0.874$ Nash-Sutcliffe Coeff. = 0.870

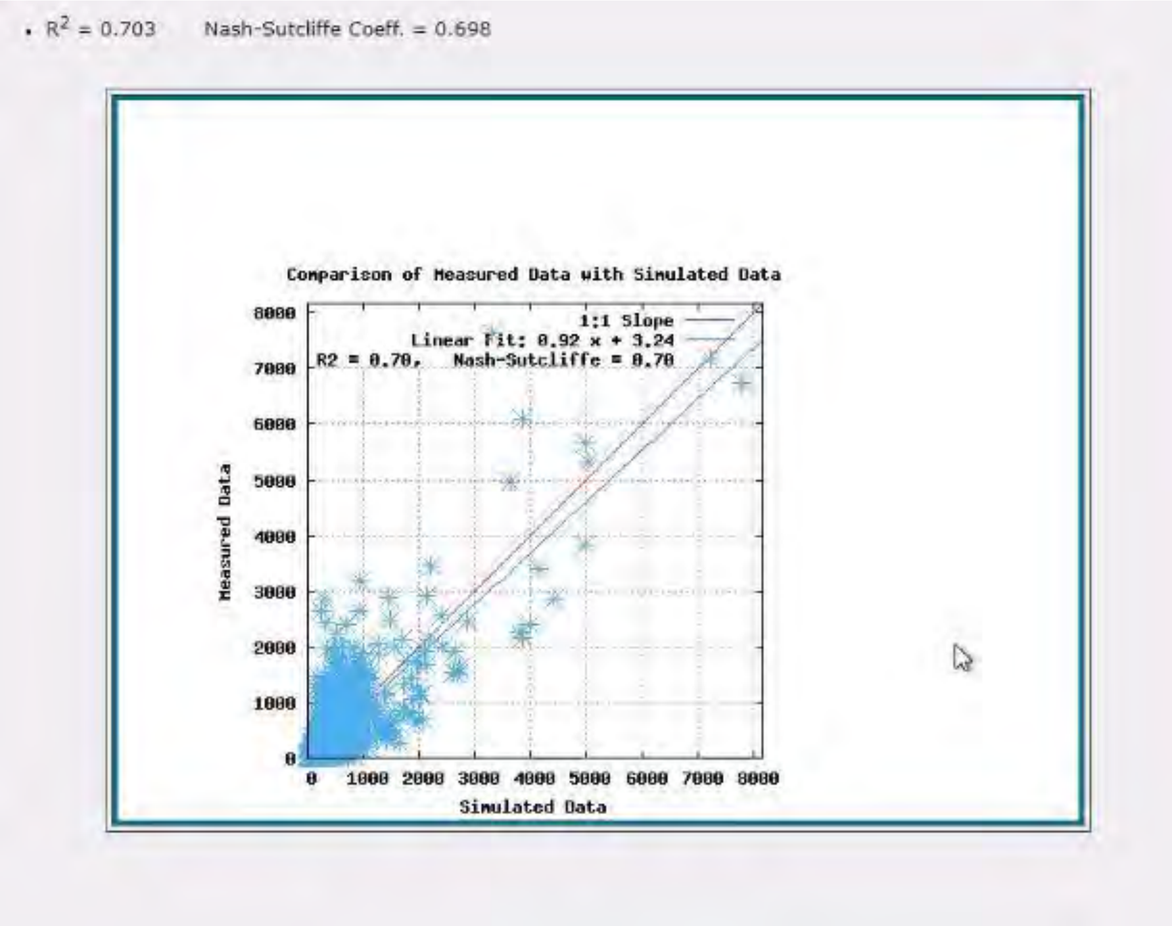


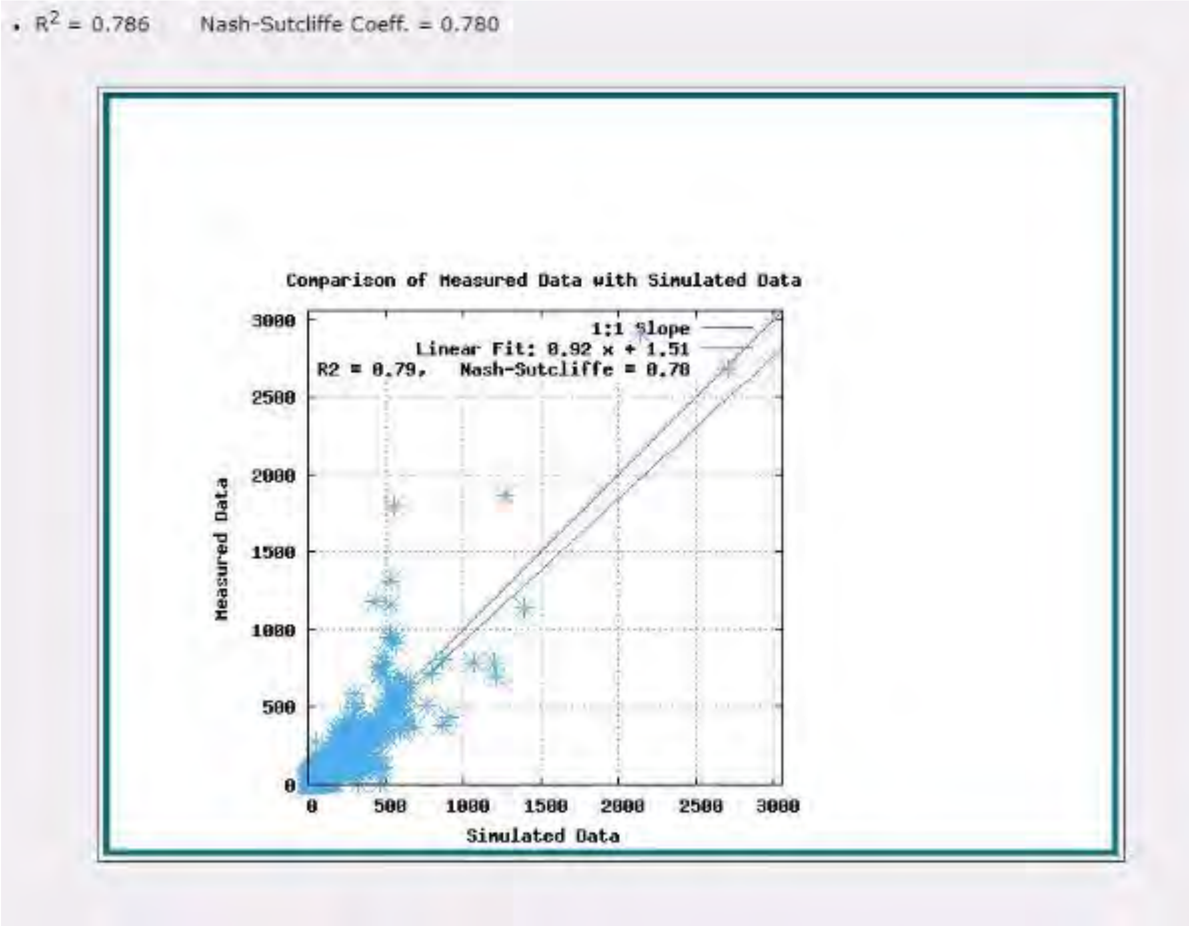
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Don Juan Bridge

NSE Daily Entire Simulation

NSE Daily low flows (Apr.-Oct)

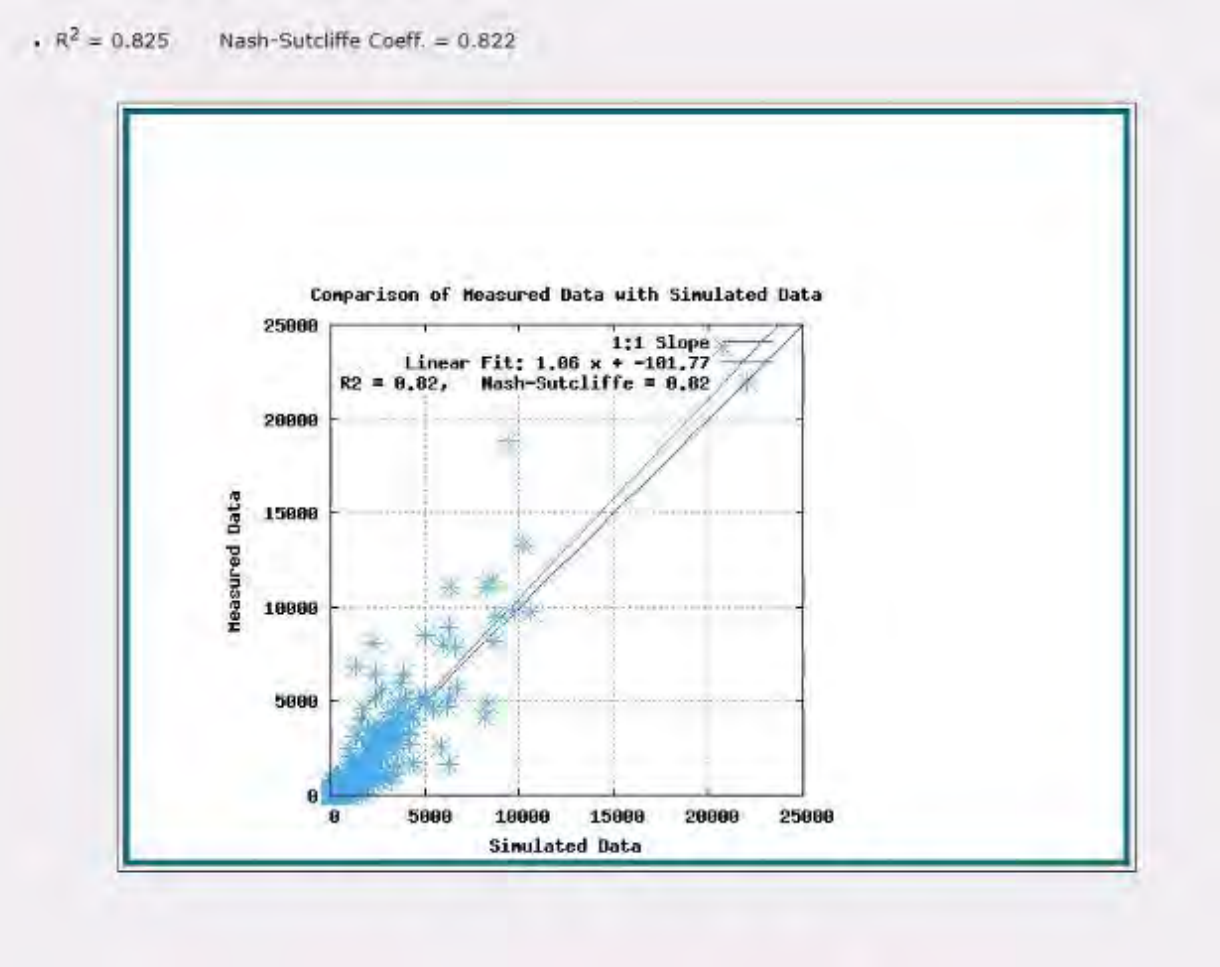




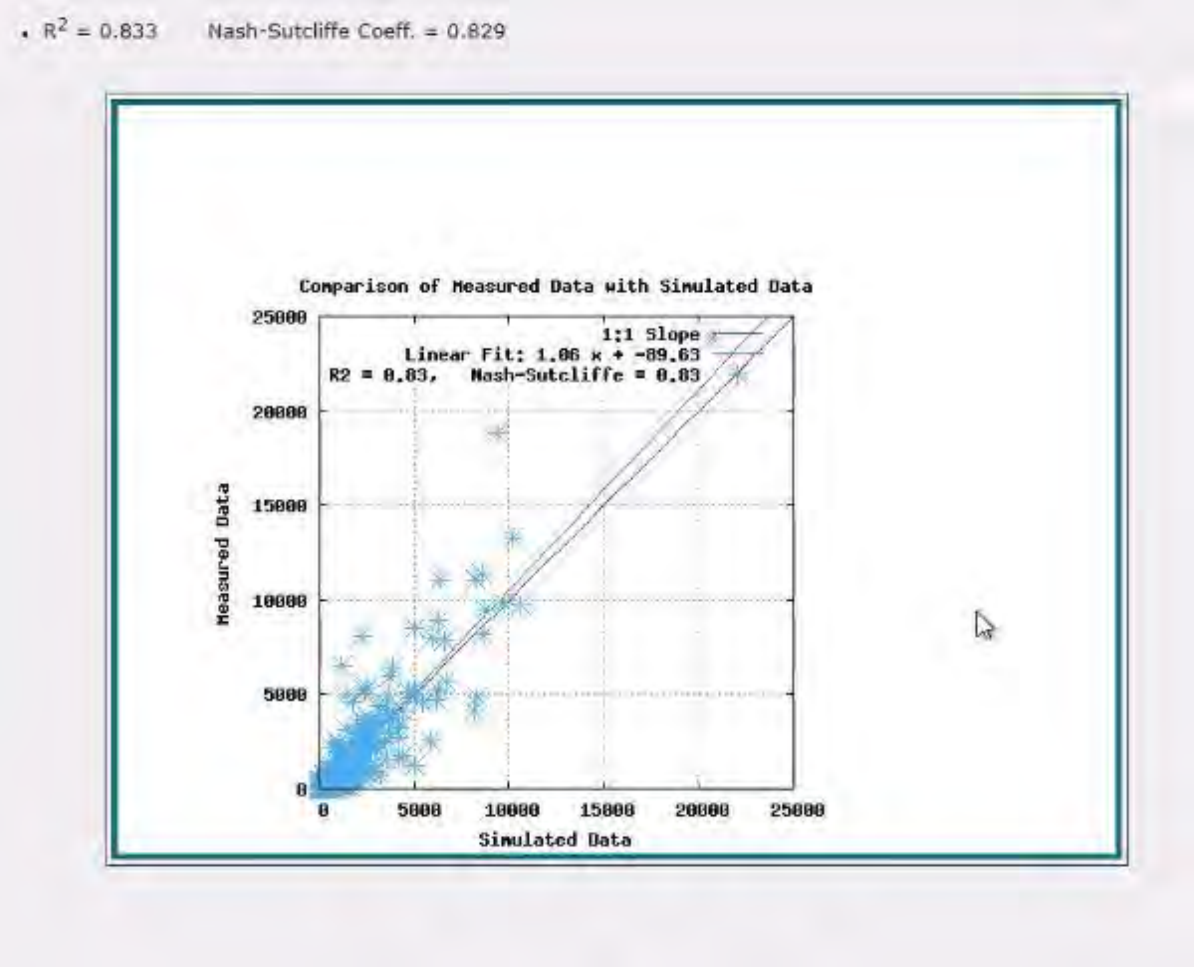
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Don Juan Bridge

NSE Weekly Entire Simulation



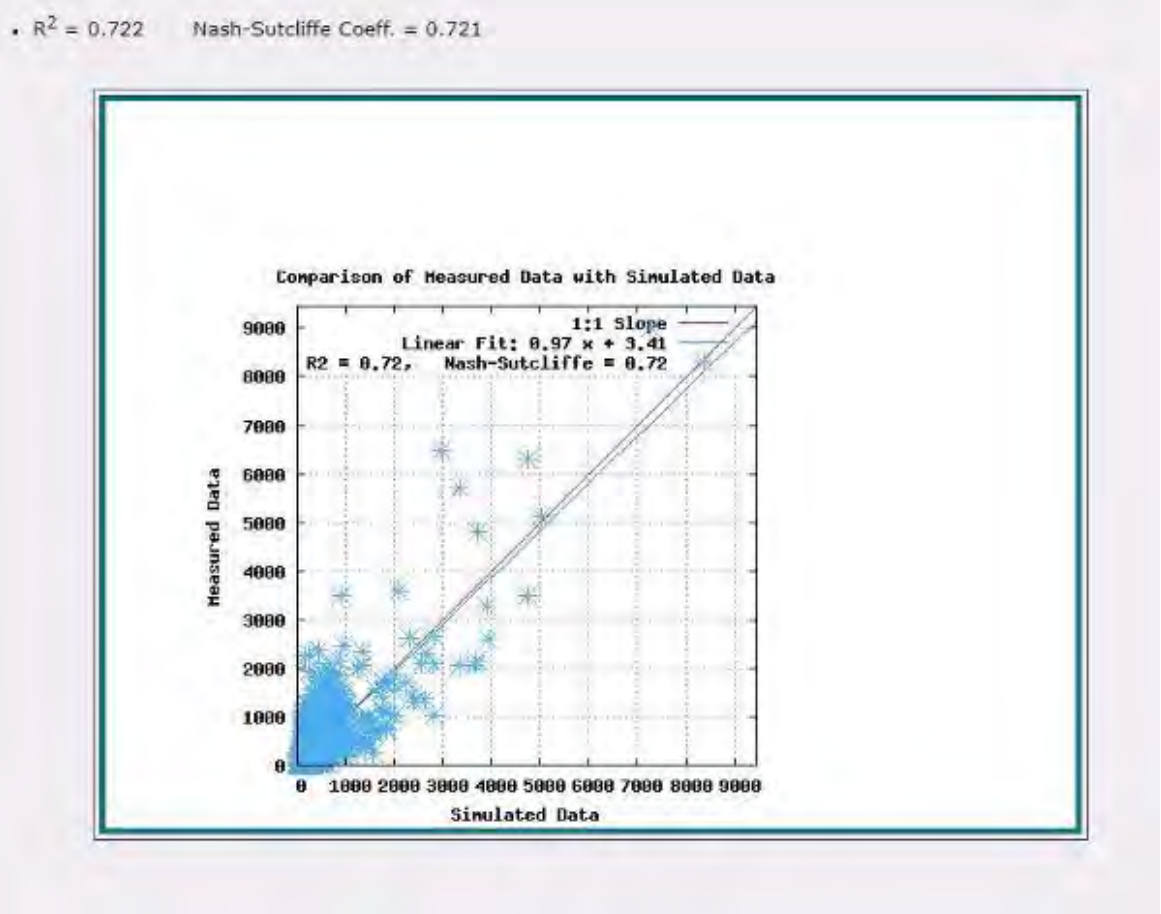
NSE Weekly low flows (Apr.-Oct)



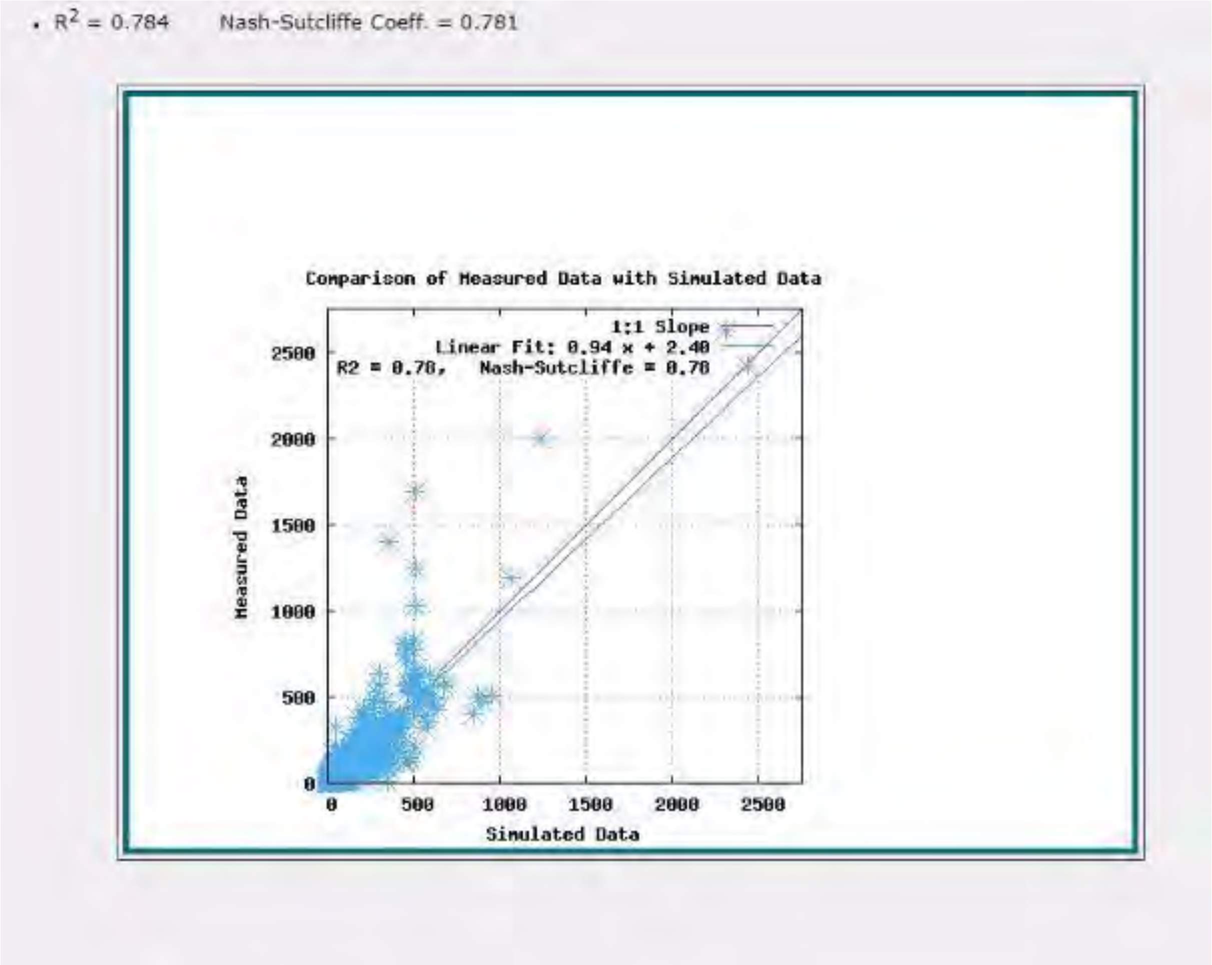
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Robles del Rio

NSE Daily Entire Simulation



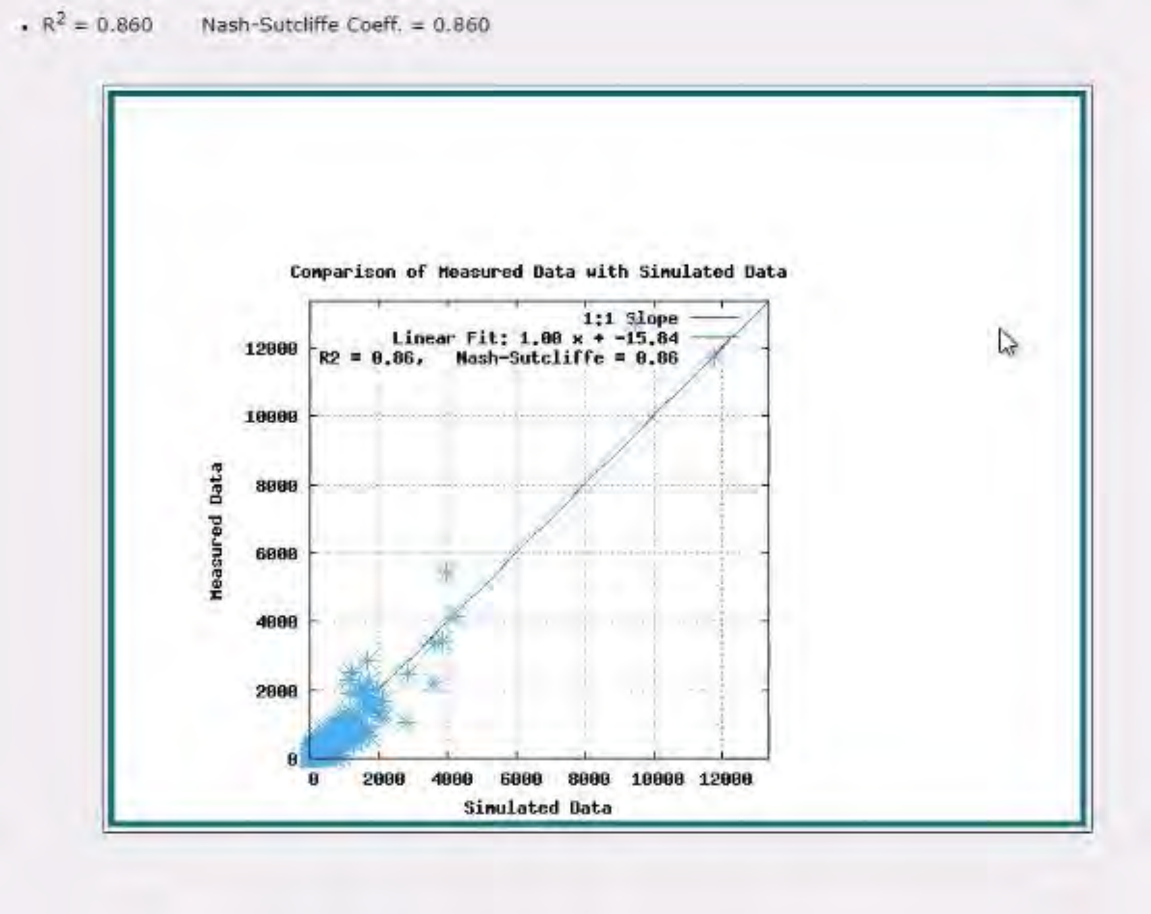
NSE Daily low flows (Apr.-Oct)



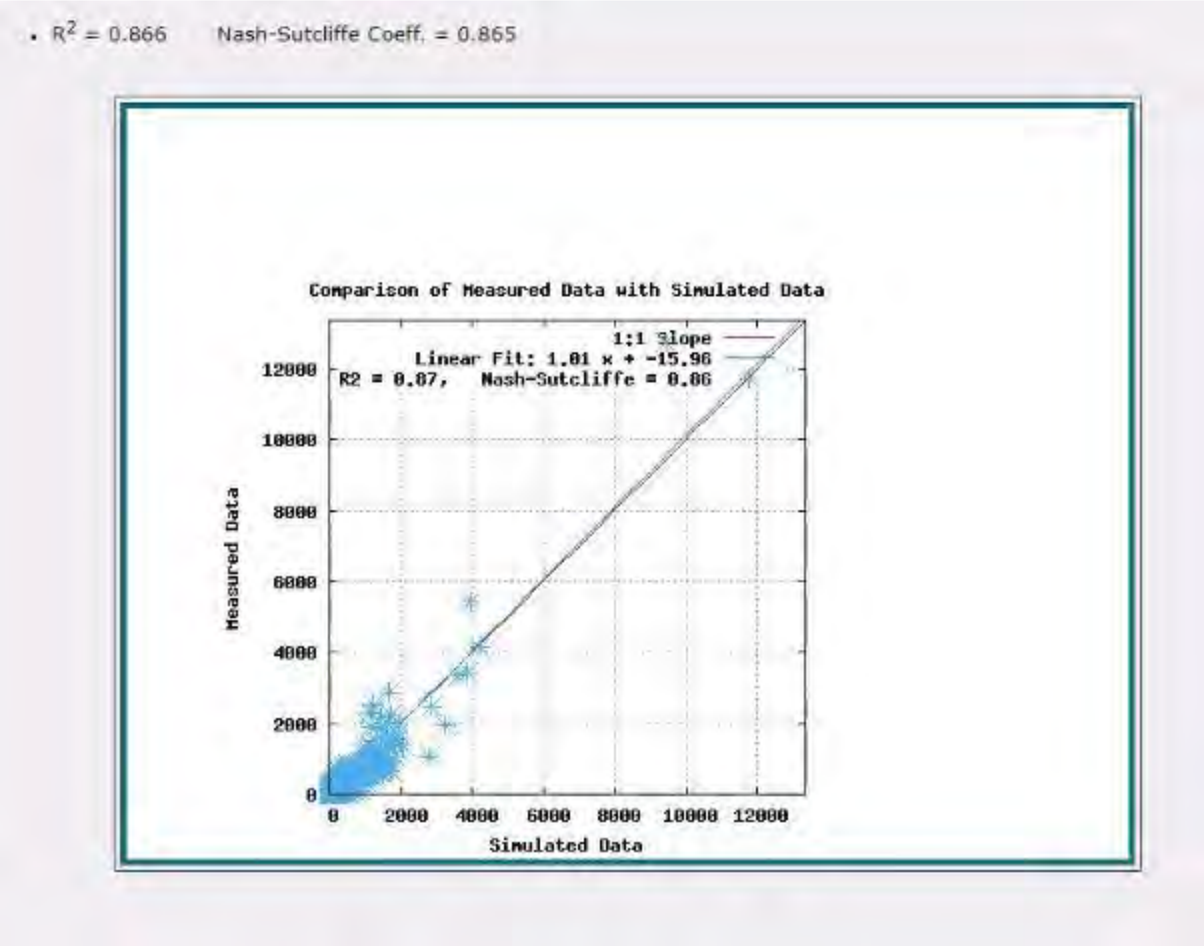
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Robles del Rio

NSE Weekly Entire Simulation



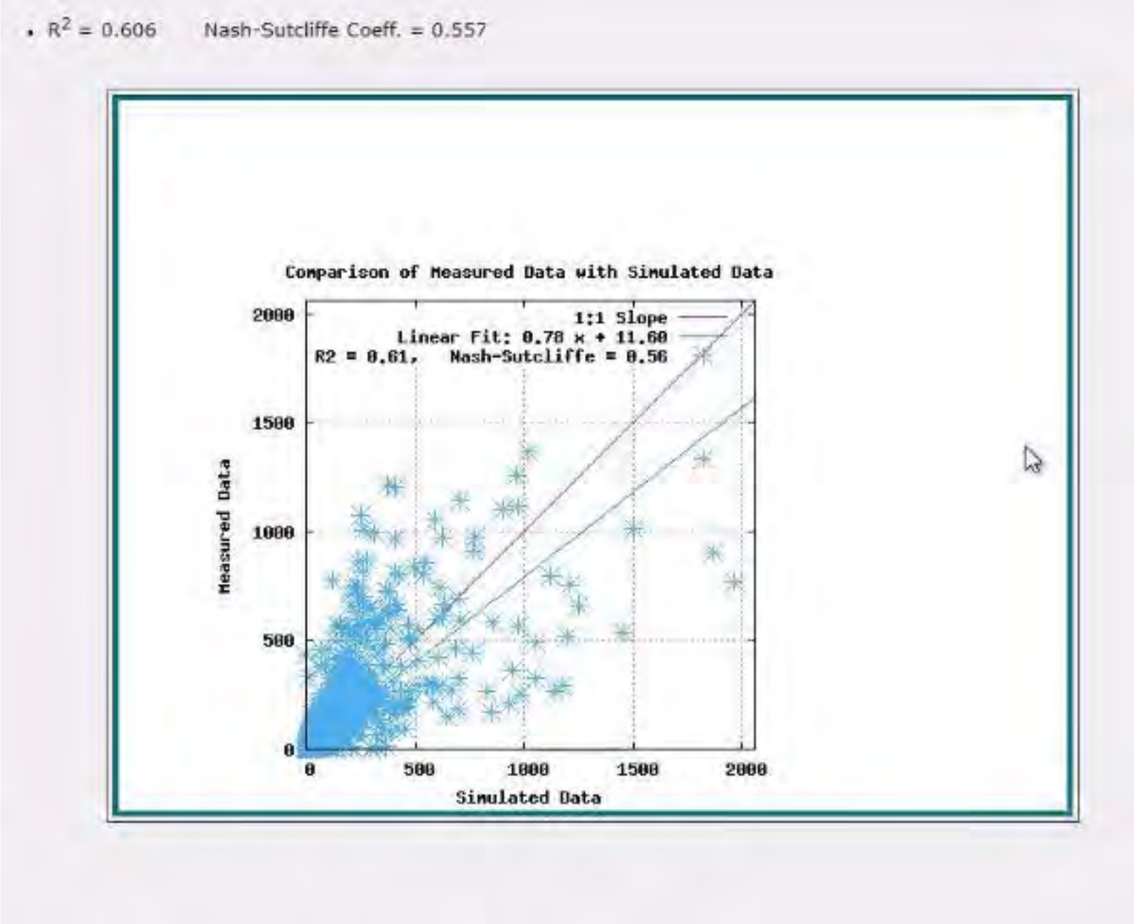
NSE Weekly low flows (Apr.-Oct)



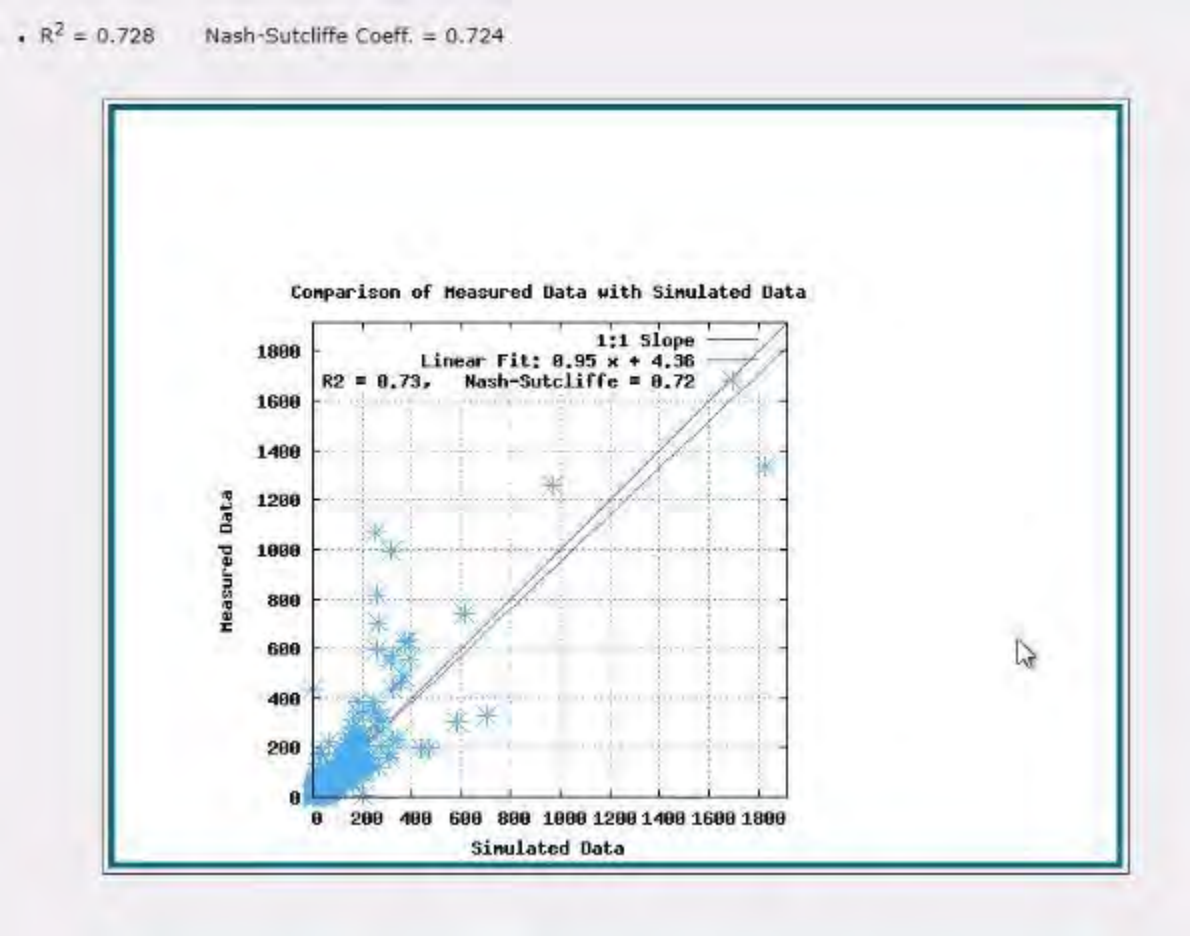
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Below Los Padres

NSE Daily Entire Simulation



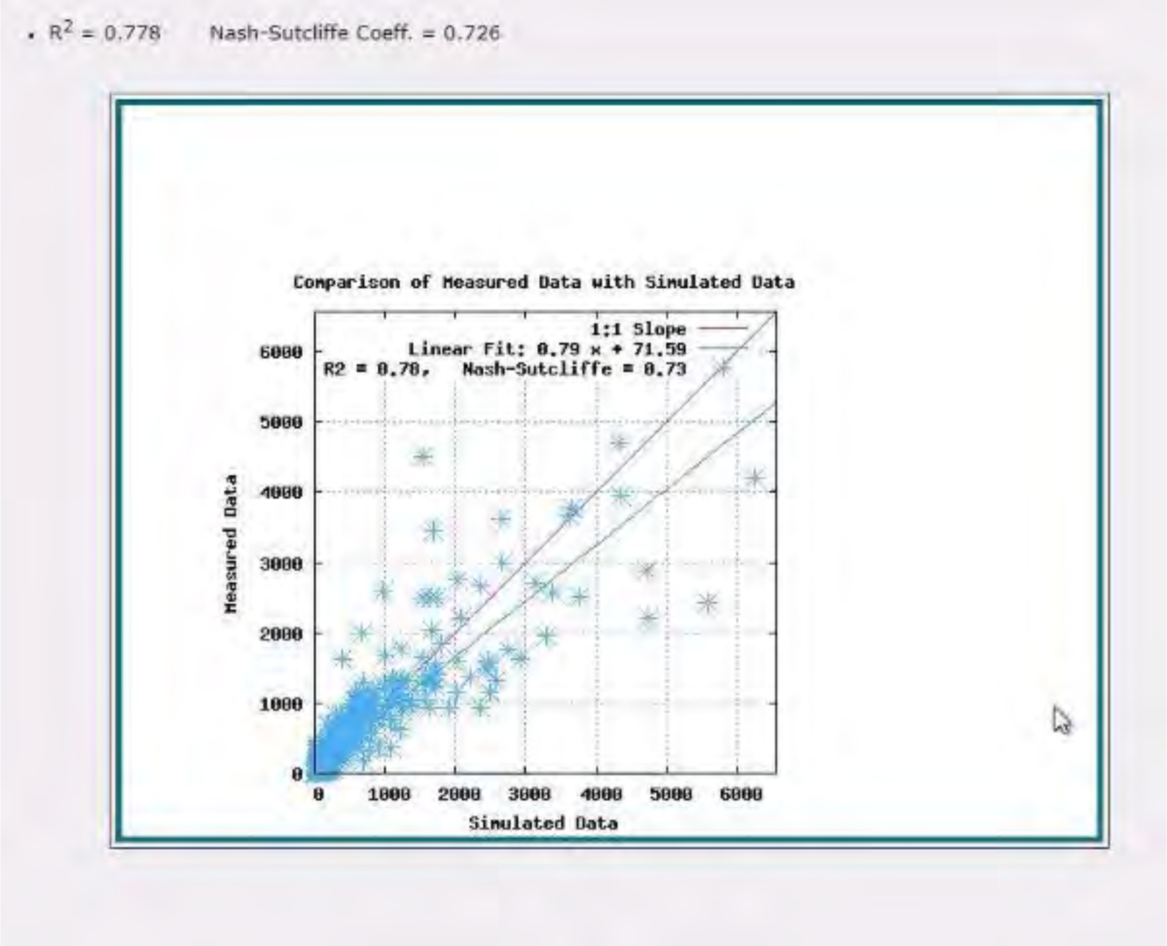
NSE Daily low flows (Apr.-Oct)



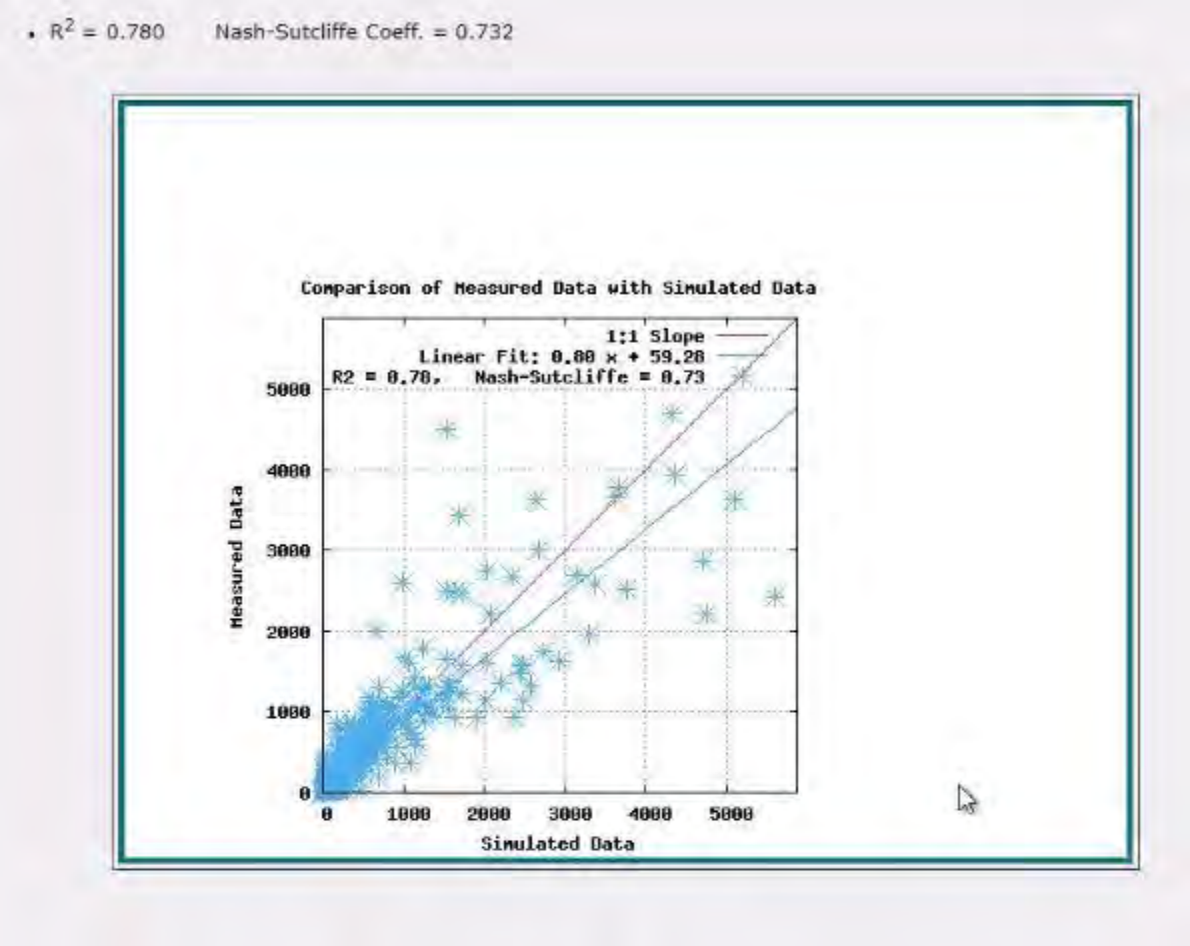
Nash Sutcliffe Efficiency Values for Different Stream Gages on Carmel River Mainstem

Below Los Padres

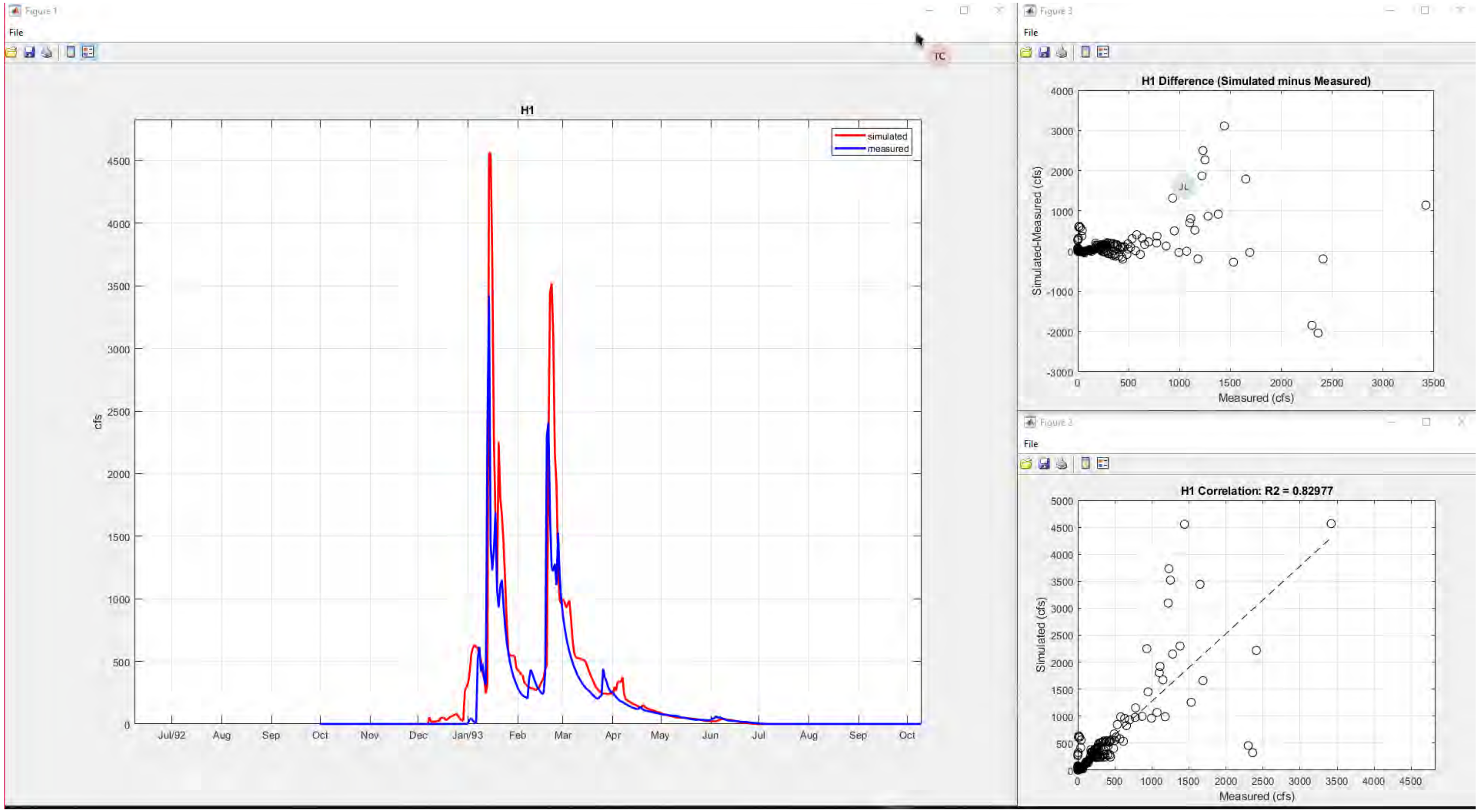
NSE Weekly Entire Simulation



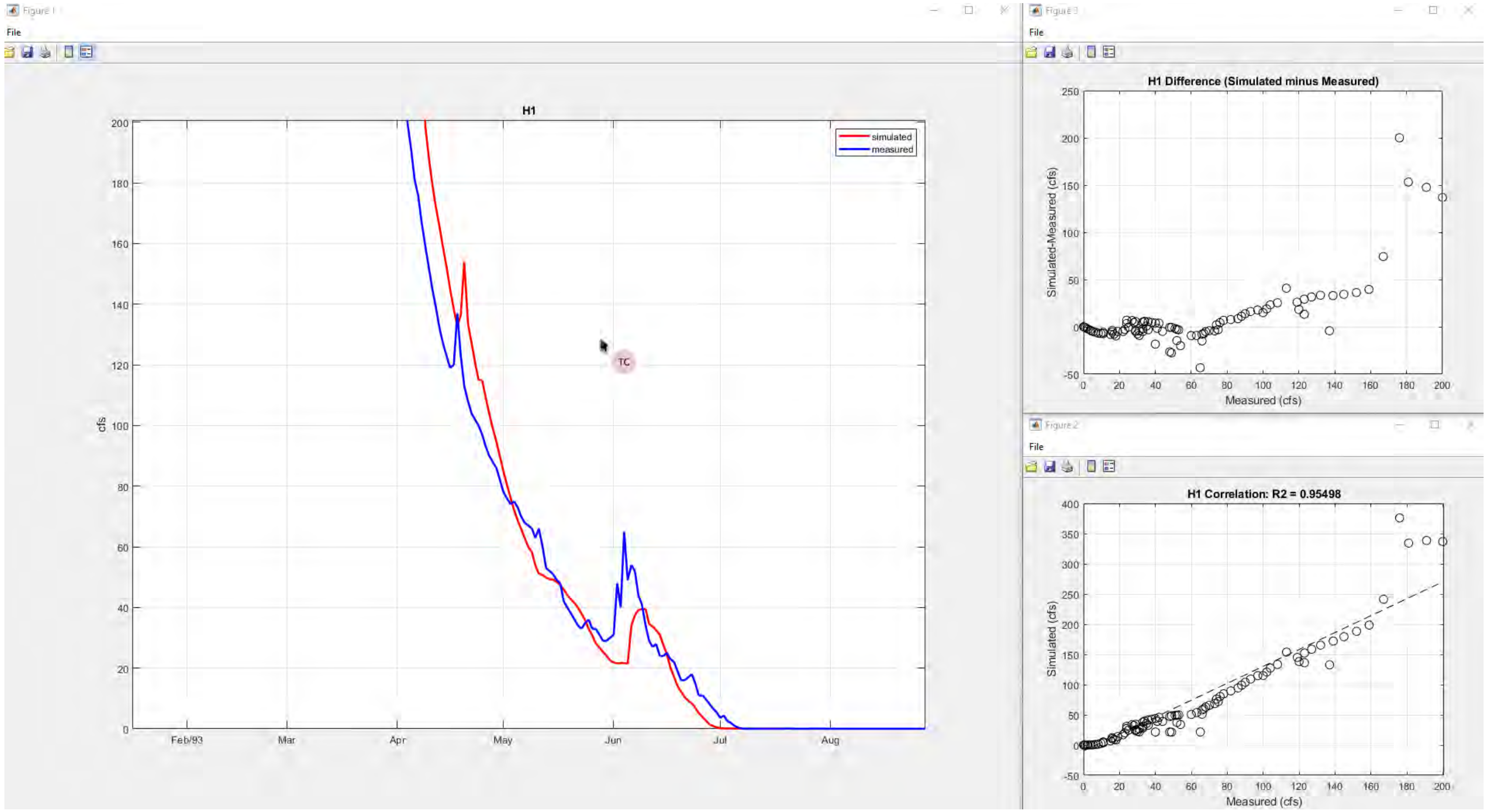
NSE Weekly low flows (Apr.-Oct)



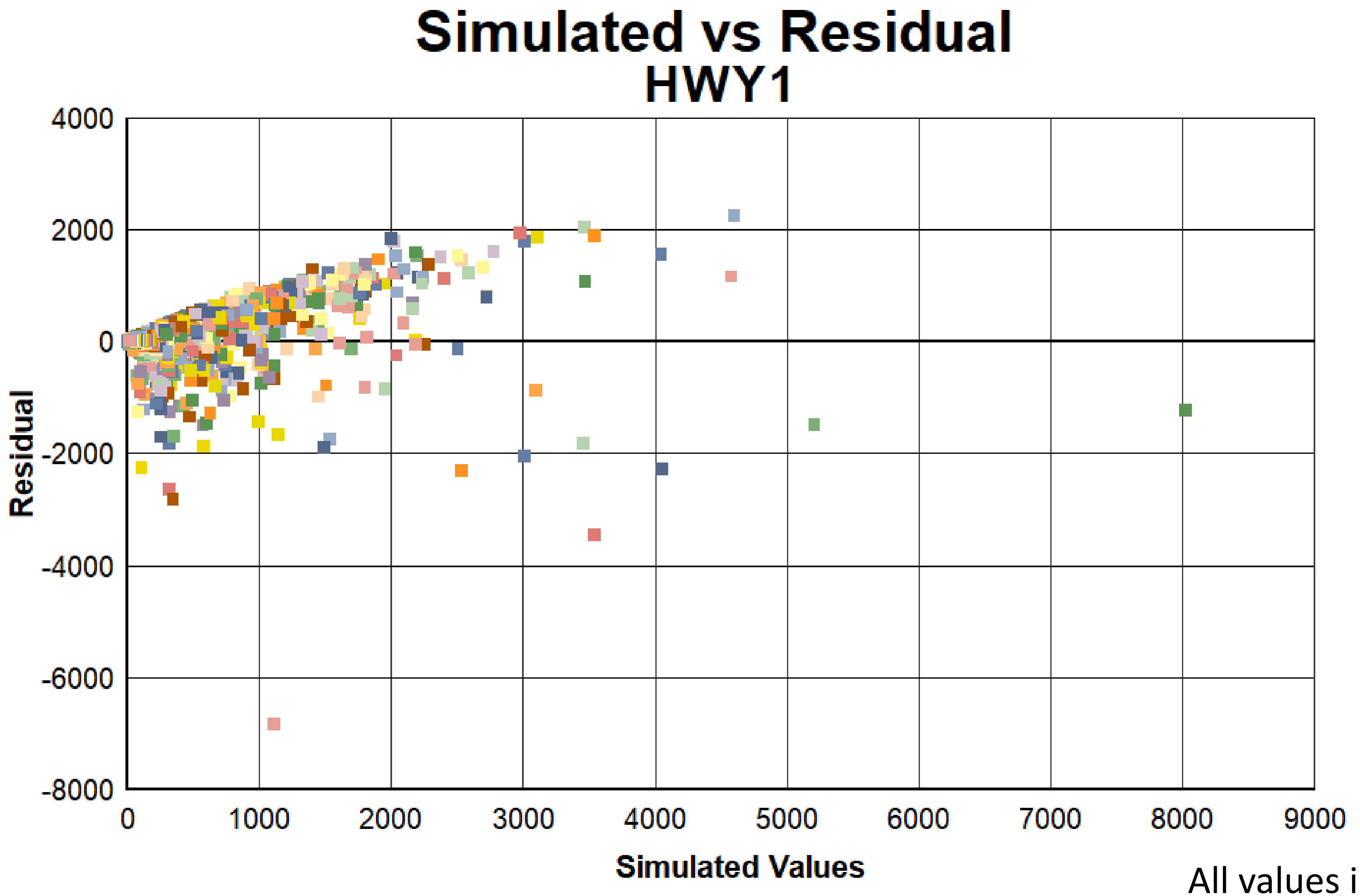
Example hydrograph for residual plots (Highway One WY 1993)



Highway One WY 1993 (flows below 200 cfs)

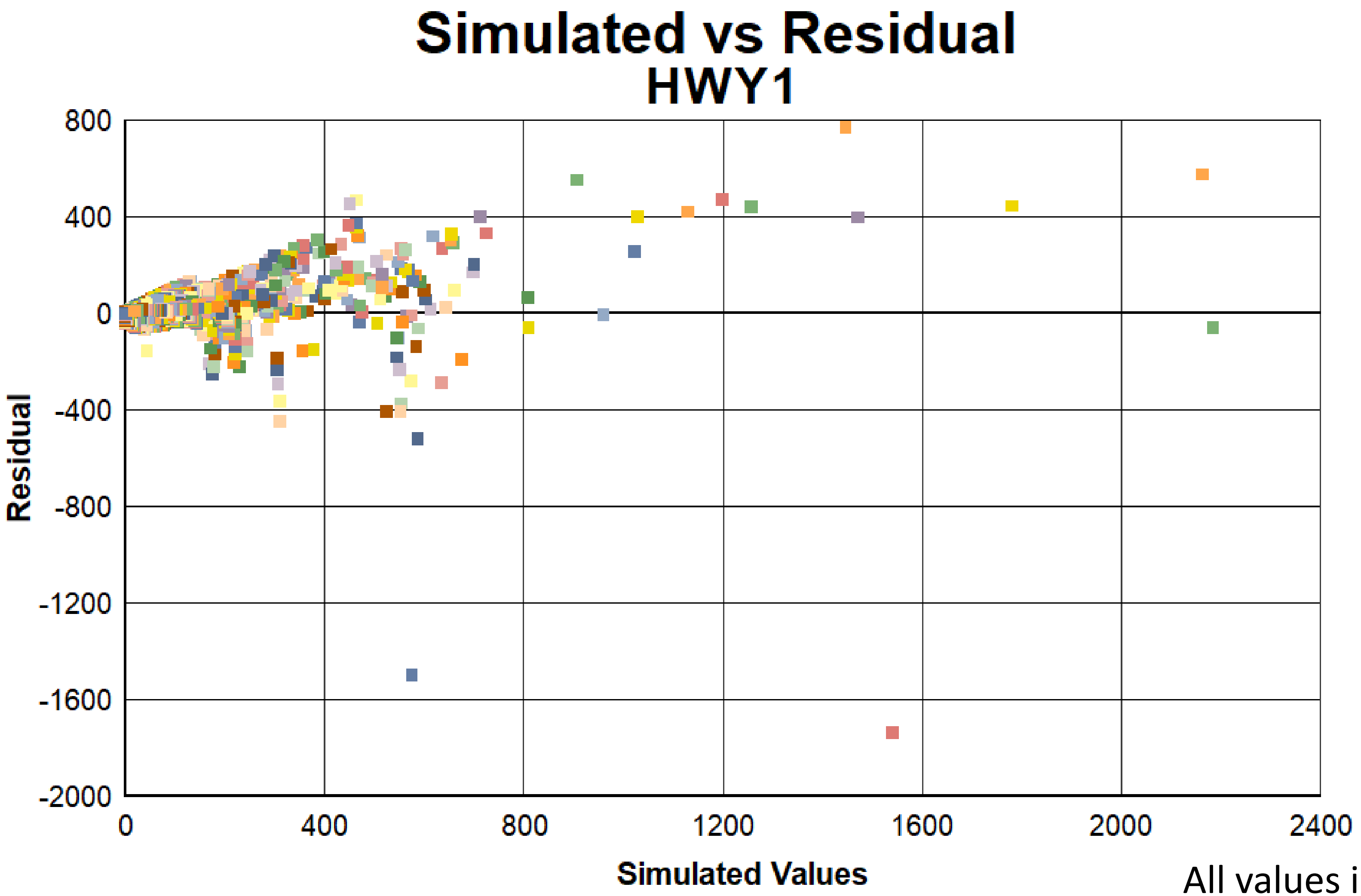


Simulated Streamflow and Residuals Entire Simulation



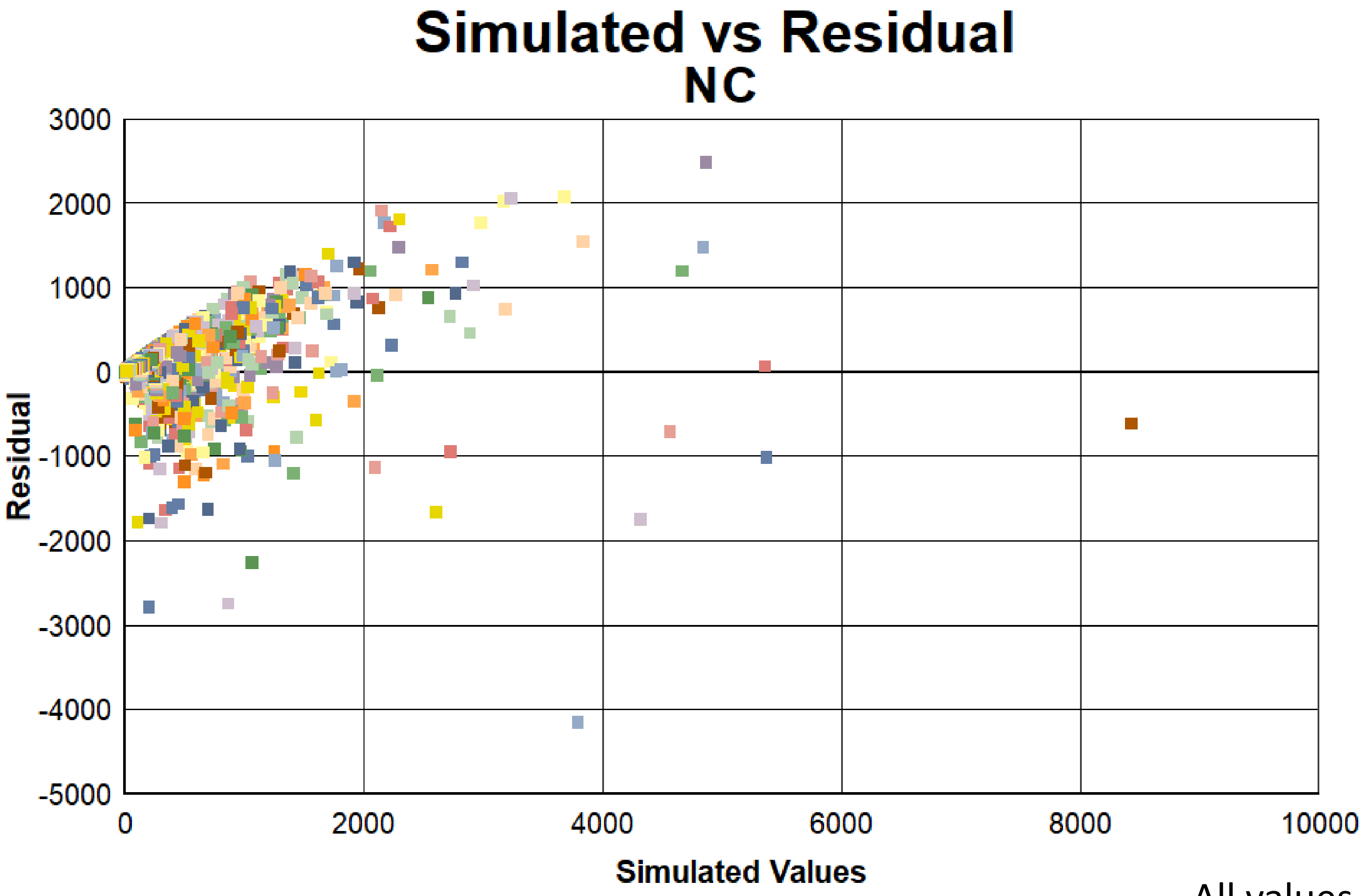
All values in cfs

Simulated Streamflow and Residuals (low flow Apr.-Oct)



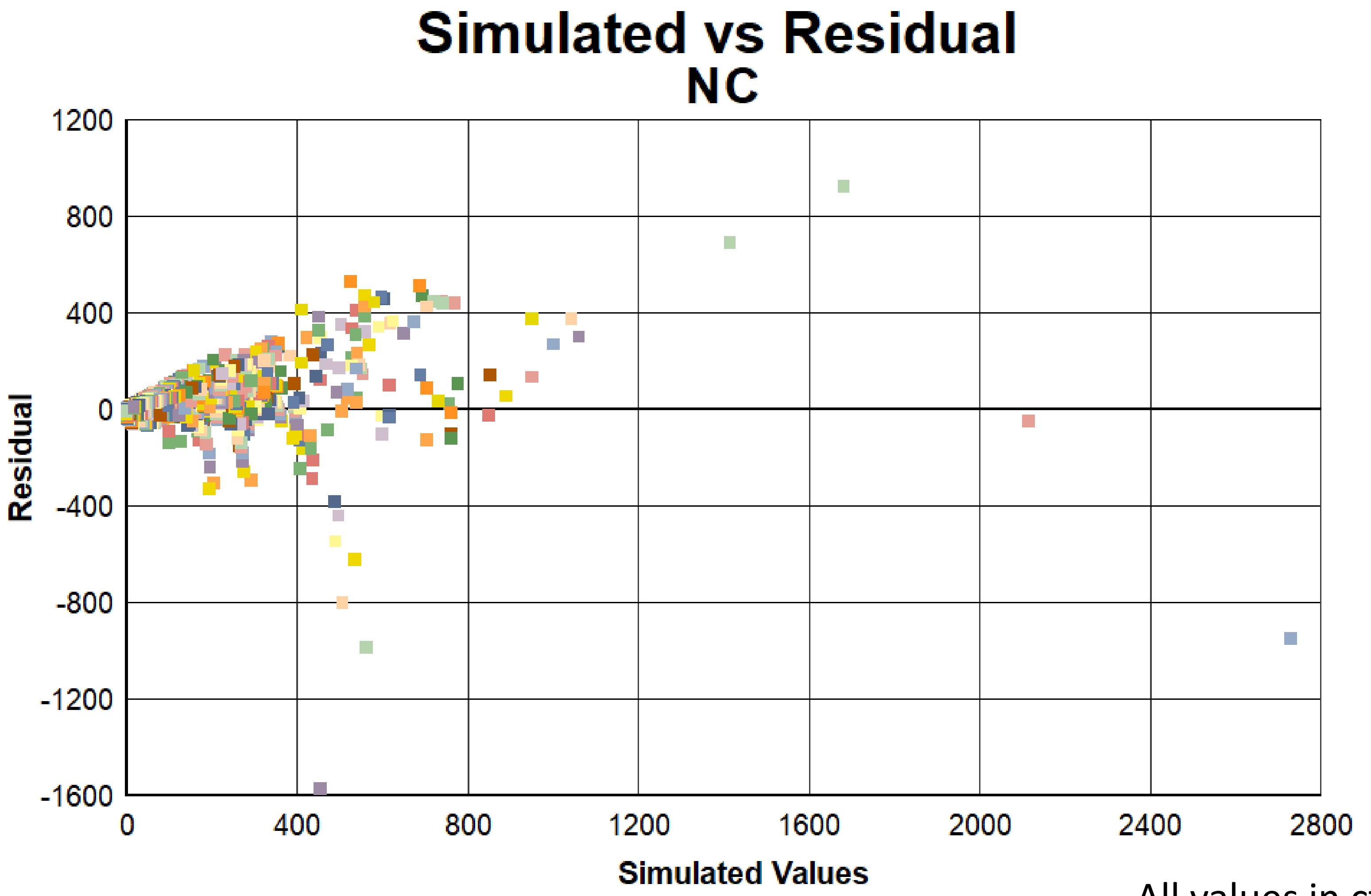
All values in cfs

Simulated Streamflow and Residuals Entire Simulation



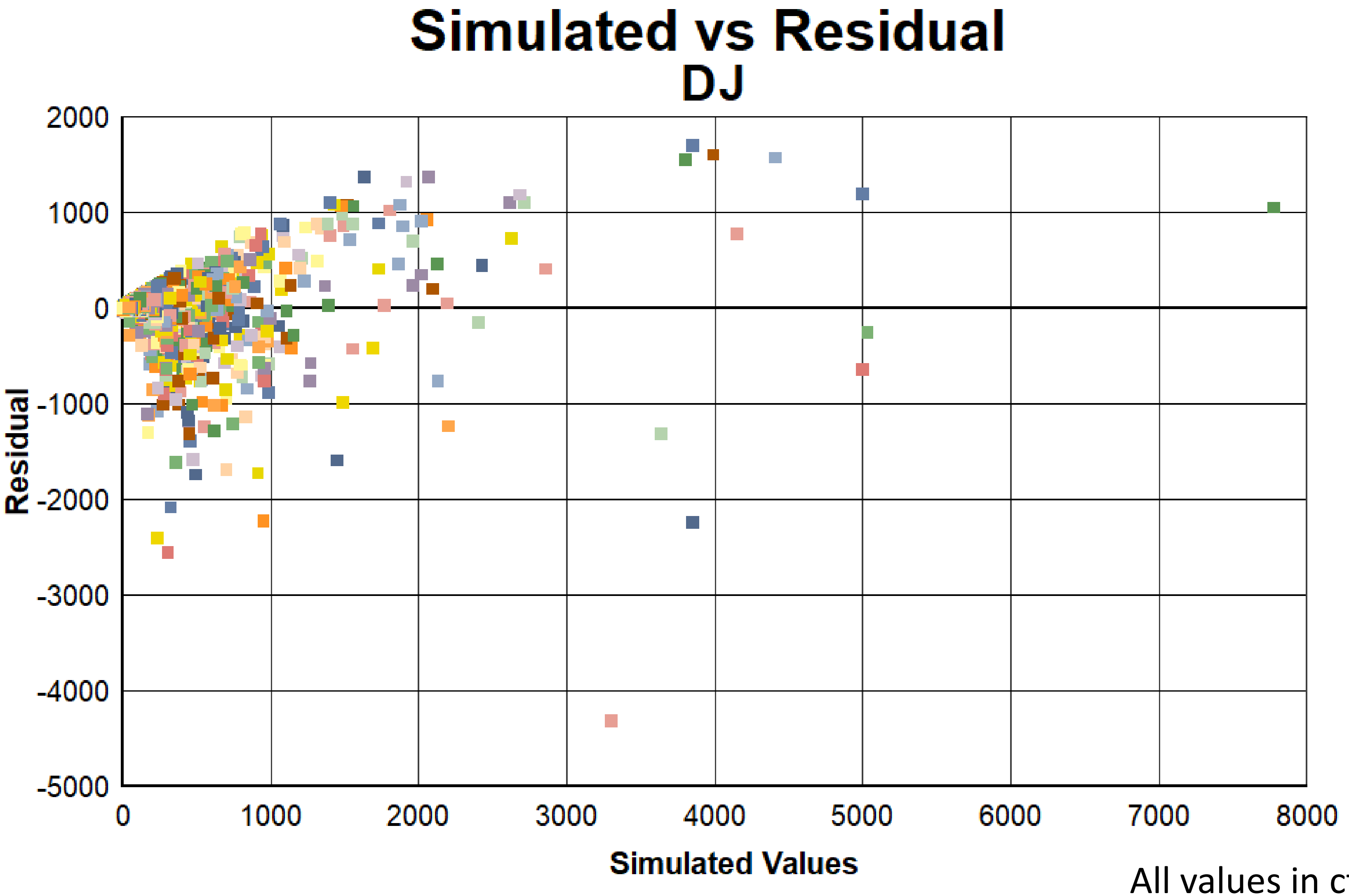
All values in cfs

Simulated Streamflow and Residuals (low flow Apr.-Oct)



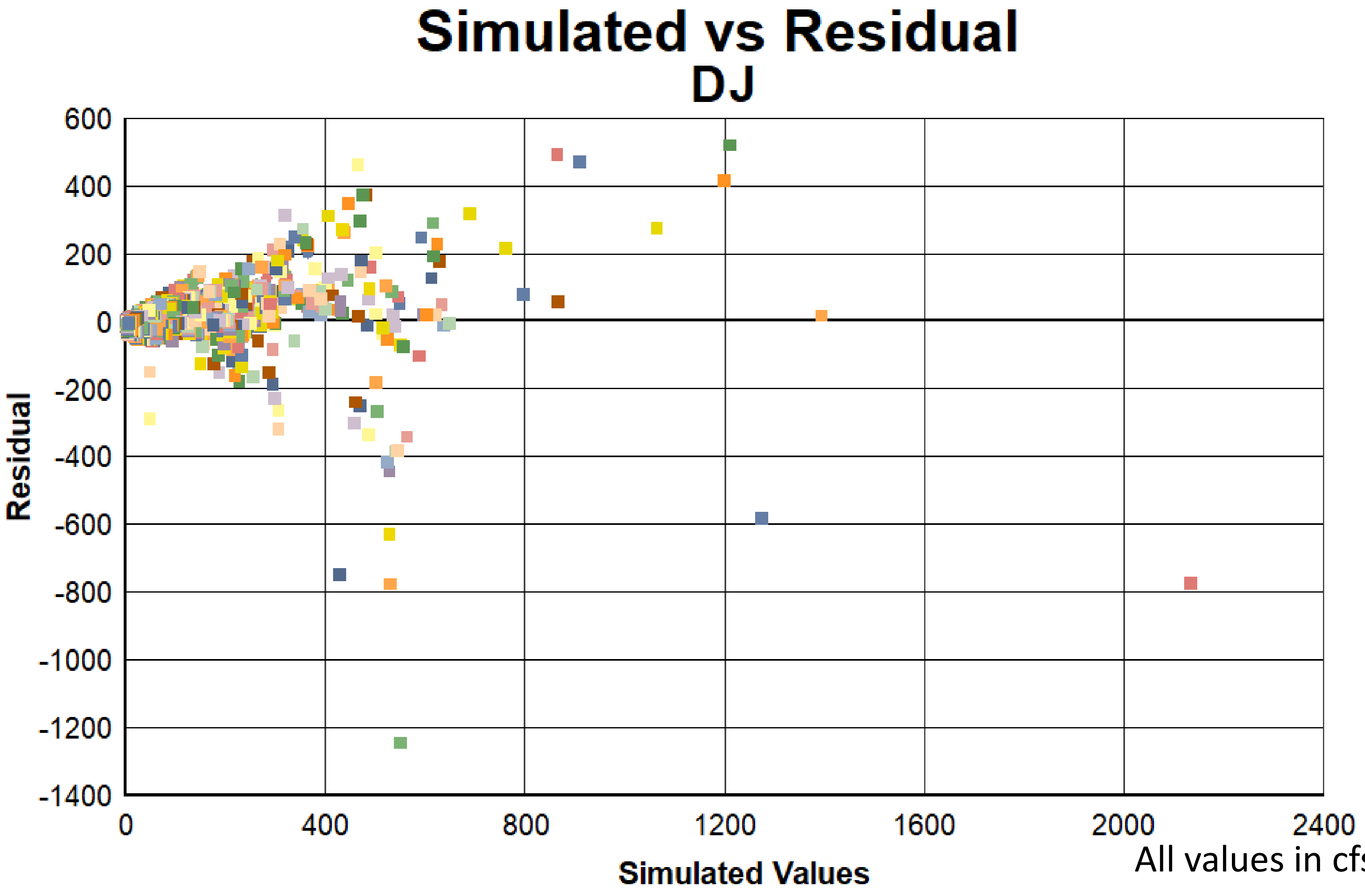
All values in cfs

Simulated Streamflow and Residuals Entire Simulation



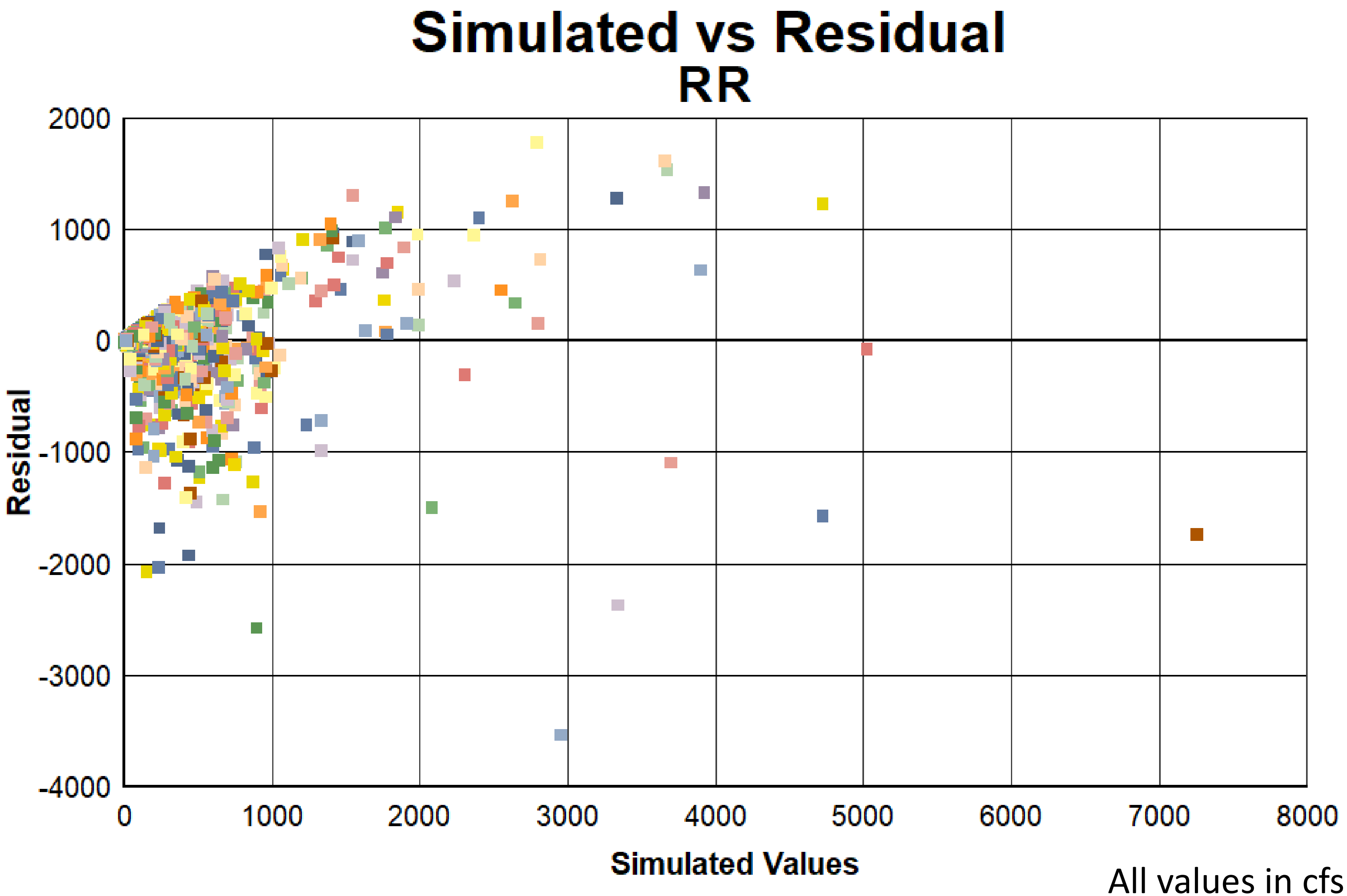
All values in cfs

Simulated Streamflow and Residuals (low flow Apr.-Oct)



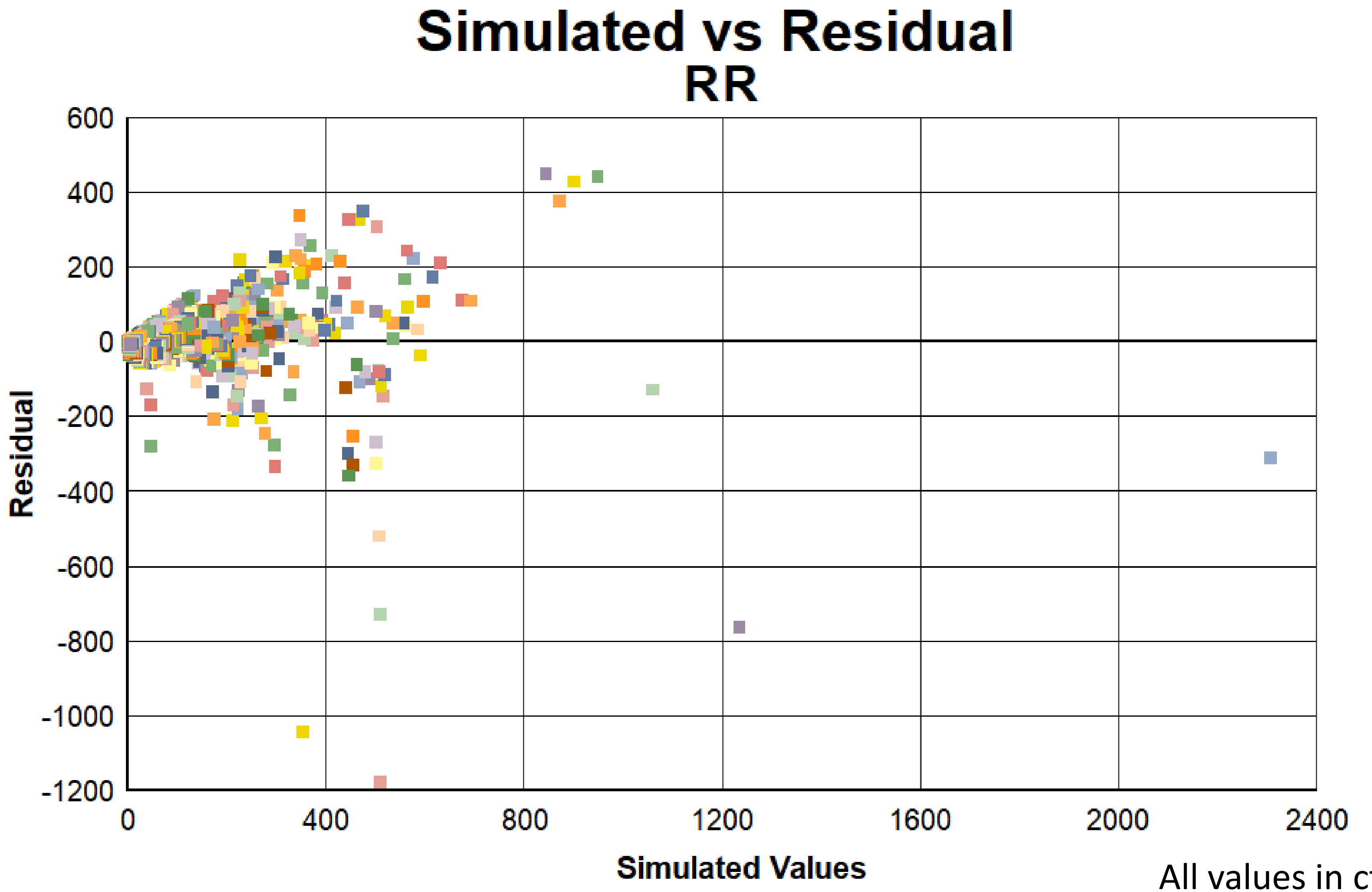
All values in cfs

Simulated Streamflow and Residuals Entire Simulation



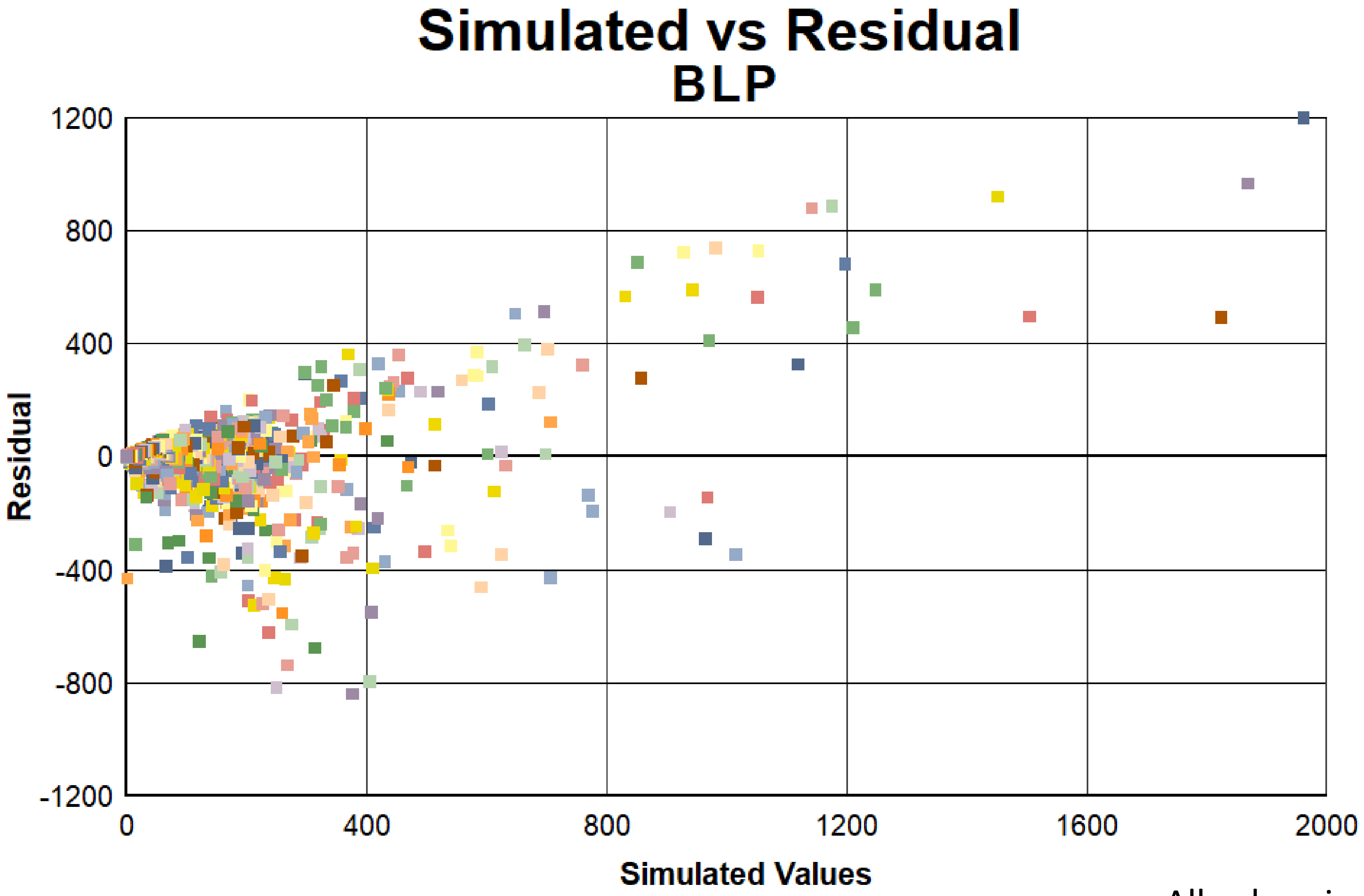
All values in cfs

Simulated Streamflow and Residuals (low flow Apr.-Oct)



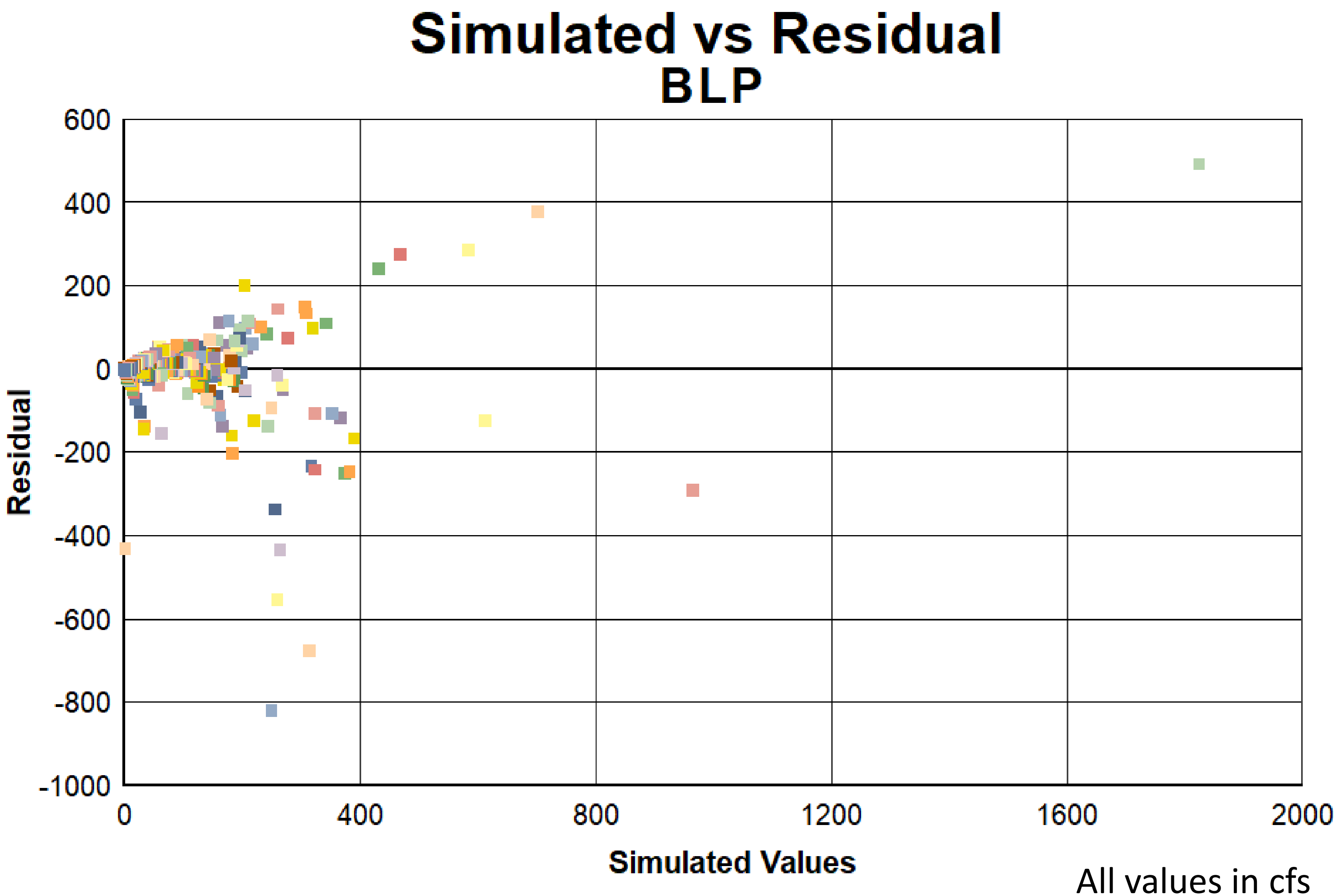
All values in cfs

Simulated Streamflow and Residuals Entire Simulation



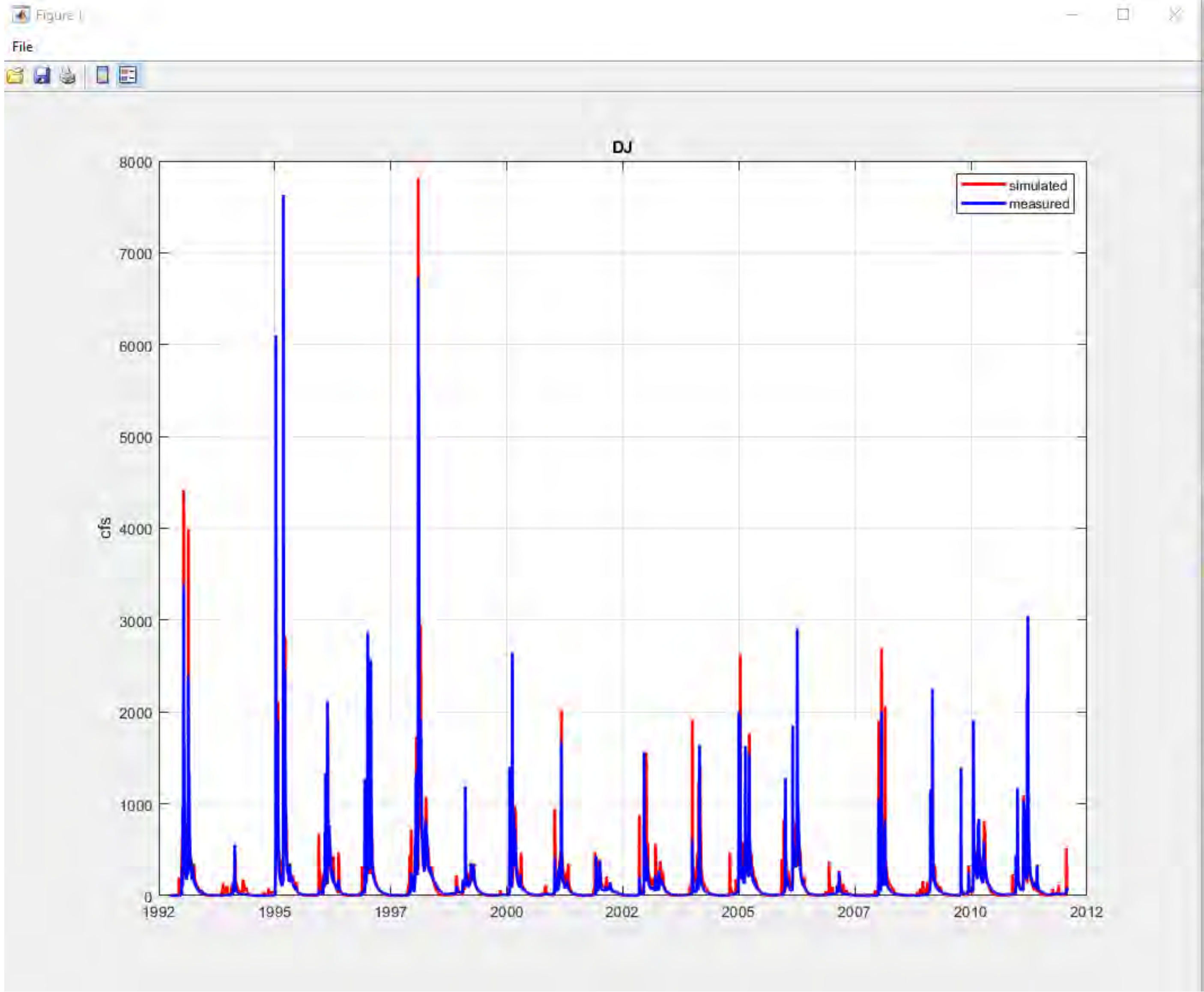
All values in cfs

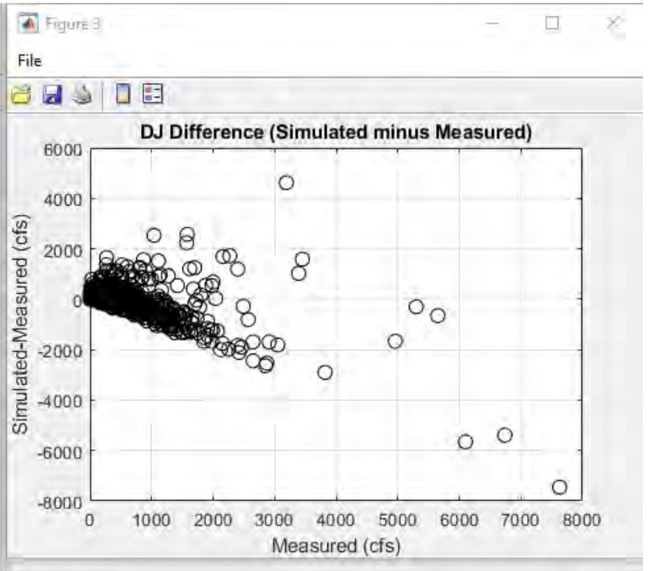
Simulated Streamflow and Residuals (low flow Apr.-Oct)

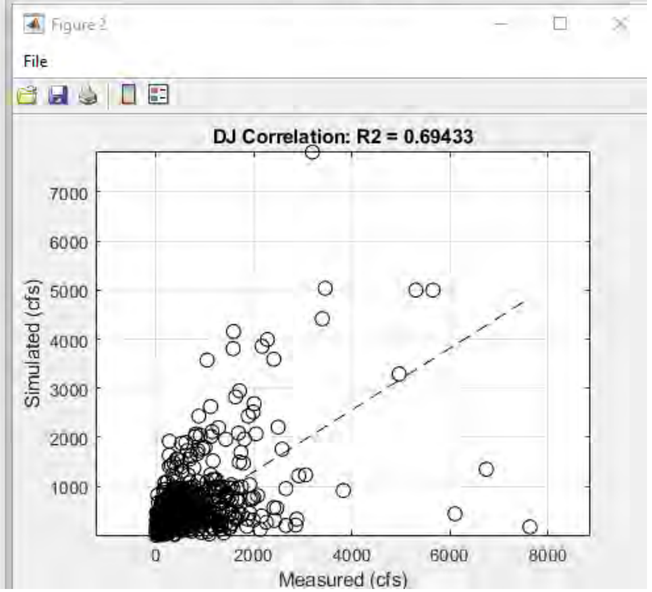


All values in cfs

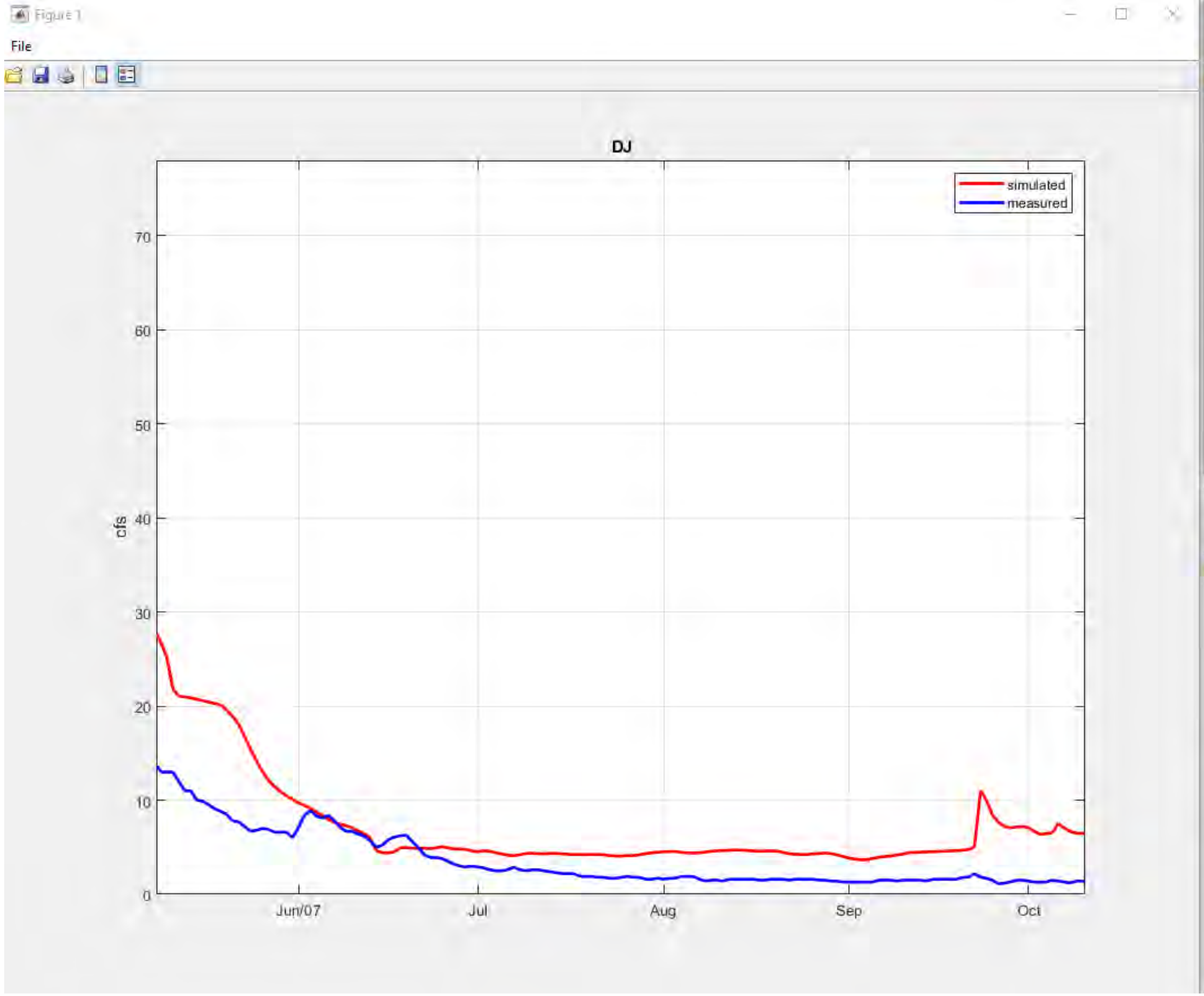
Don Juan Gage Entire Simulation

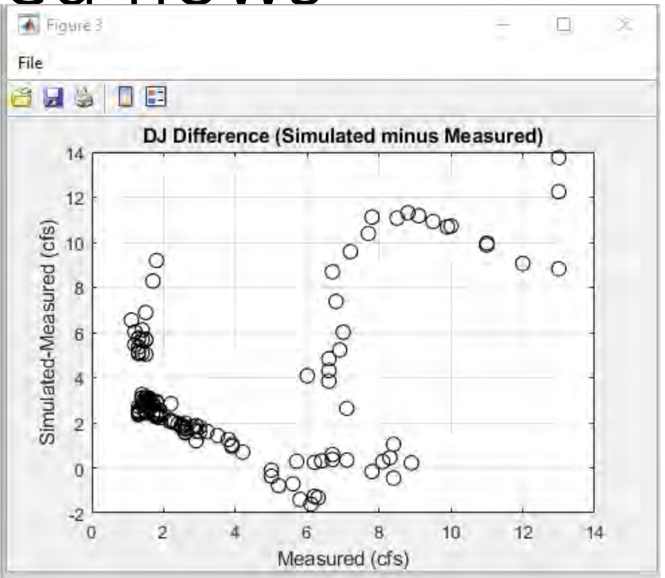


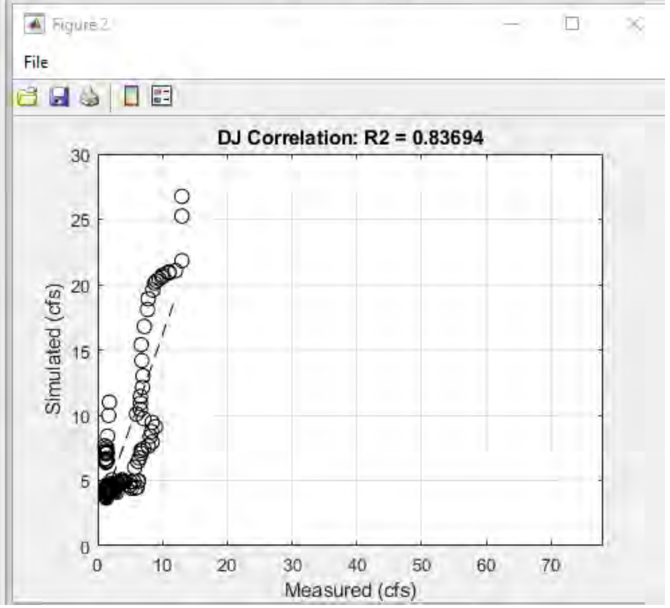




Don Juan Water Year 2007 (dry year) does not go dry in simulated flows or measured flows

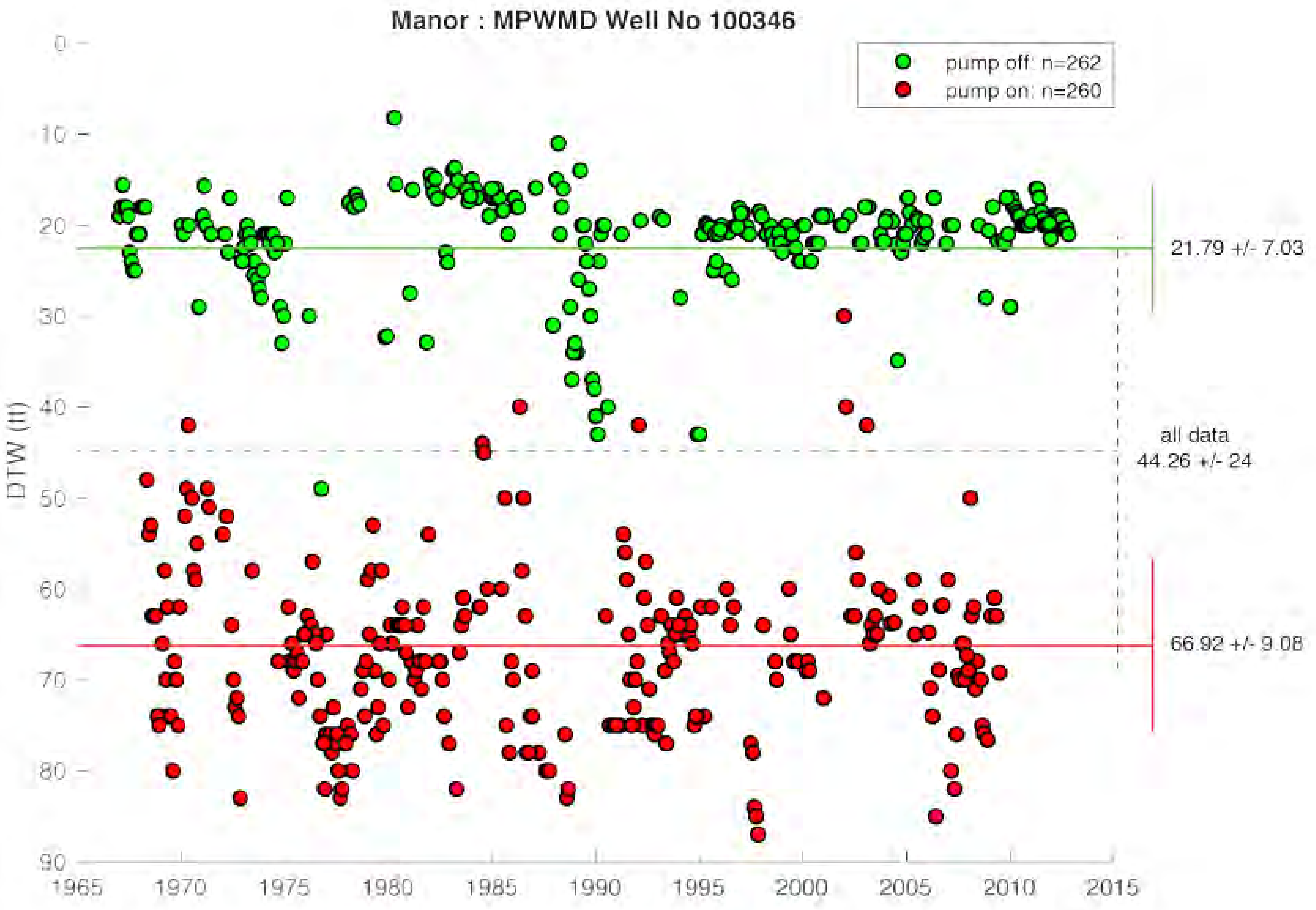






Groundwater Observations – 60 Wells

• Tier 1 Wells – Monitor wells with little pumping influence – Used in PEST for Calibration.	• Good static water levels representative of aquifer system.
• Tier 2 Wells – Monitor wells under direct pumping influence and Domestic pumping wells – Weighted lightly in calibration.	• Water levels effected by municipal and domestic pumping patterns, less representative of aquifer system.
• Tier 3 Wells – Municipal pumping wells – Not used in Calibration, but kept in observations file to show effects of unknown pumping on water levels.	• Extreme fluctuations in observed water levels from changes in daily pumping, not representative of aquifer system and unusable in model calibration.



Manor : MPWMD Well No 100346
pump off: n=262
pump on: n=260
DTW (ft)
21.79 +/- 7.03
all data
44.26 +/- 24
66.92 +/- 9.08
0
10
20
30
40
50
60
70
80
90
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Statement on groundwater levels

- Model calibration requires a tradeoff between fitting measure groundwater levels at various locations and measured streamflows. Furthermore, there are uncertainties in measured groundwater levels that require varying weights be applied to each well that consider the impacts of
- 1) pumping rates in production wells that are affected by well construction and the daily time and rate of pumping that cannot be reproduced in the model with monthly pumping rates;
- 2) local heterogeneities in the vicinity of the well screen that have a very local impact on how water levels respond to pumping;
- 3) effect of local topography around the well that are not represented in average altitude of the model cells;
- 4) perched aquifers in the upland regions that are not represented in the model. Results comparing simulated and measured heads indicate that for many wells, especially in monitoring wells around the river, the RMSE is less than 5 m, and in many cases less than 2 m. This indicates that the model is matching measured groundwater levels that are not impacted by well construction affects and local heterogeneities. Forcing (calibrating) the model by adjusting aquifer properties locally around wells is not likely to improve the model's ability to simulate the capture of streamflow by wells in the lower part of the basin.
- It was the goal of the modeling group to focus on the lower flows and try and match the observed springtime recession in streamflow.

Observation Wells by Tier

Heavily Weighted

Tier	Well Name	RMSE	Well Type
1	CVR 5	0.41	Monitor
1	SP HWY 1	0.95	Monitor
1	Lagoon P1 W	0.97	Monitor
1	CAWD Rio North	0.91	Monitor
1	Womble ABD	1.15	Abandoned
1	SP Nr CAWD West (D)	1.58	Monitor
1	Odello West - Sanitary	1.66	Abandoned
1	Rancho Canada West	1.71	Monitor
1	Boronda	0.87	Monitor
1	Valley Greens	1.80	Monitor
1	CAWD Dewtr	1.82	Monitor
1	Hernstadt	2.02	Abandoned
1	Russell 2	2.13	Abandoned
1	Russell 4	2.33	Abandoned
1	Little League 1	2.37	Monitor
1	Via Hellechos	2.57	Monitor
1	Well E	2.73	Monitor
1	Garzas 4	2.81	Abandoned
1	CVR 8	2.82	Monitor
1	Brookdale	2.98	Monitor
1	Coast Ranch	3.04	Abandoned
1	Reimers1	3.20	Abandoned
1	CVR 1	3.42	Monitor
1	Williams North	3.44	Monitor
1	Robles 1	3.80	Abandoned

Lightly Weighted

Tier	Well Name	RMSE	Well Type
2	Odello East Inactive	4.31	Abandoned
2	Rubin	4.36	Domestic
2	Magnasco 2	4.57	Domestic
2	Coyote US	4.69	Abandoned
2	Scarlet 6	4.72	Municipal
2	Scarlett 1	4.76	Municipal
2	Williams South	4.81	Monitor
2	CV High #1	4.91	Monitor
2	Los Laureles 6	5.43	Municipal
2	Panetta 1	5.85	Municipal
2	Berwick 9	6.00	Municipal
2	Dick Monitor	6.37	Domestic
2	Scarlett 2	6.50	Municipal
2	Scarlett 8	6.63	Municipal
2	Los Laureles 5	6.81	Municipal
2	San Carlos 1982	7.61	Municipal
2	Schulte Prod	7.63	Municipal
2	Panetta 2	8.65	Municipal
2	Reimers	8.83	Domestic
2	Mandleman	9.74	Domestic

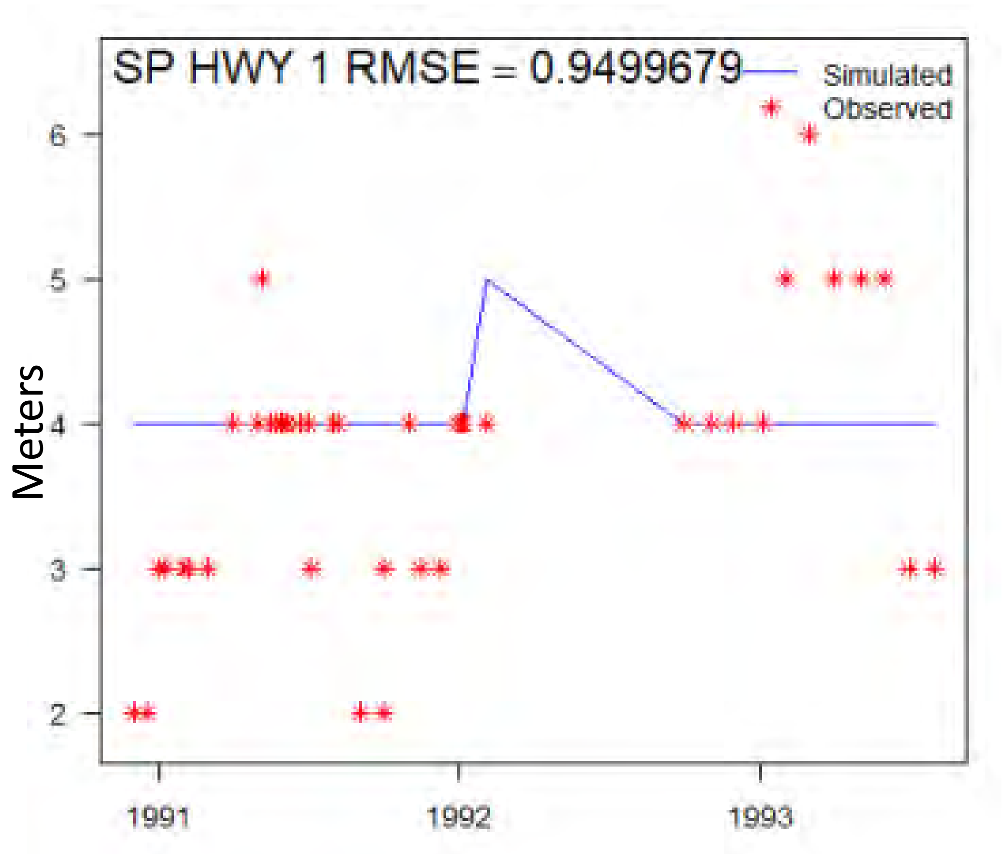
Not used for Calibration (just output)

Tier	Well Name	RMSE	Well Type
3	Center St.	9.79	Monitor
3	Berwick 8	10.05	Municipal
3	Cypress	10.39	Municipal
3	Druid Hills	11.83	Domestic
3	Manor	13.98	Municipal
3	Rancho Fielsa 1	14.53	Municipal
3	Schulte RD	15.84	Domestic
3	Begonia 2	16.08	Municipal
3	Berwick 7	17.05	Municipal
3	Rancho Canada 1	17.45	Municipal
3	Rancho Fiesta 2	24.98	Municipal
3	Sweeney	28.47	Domestic
3	San Carlos	31.33	Abandoned
3	Pearce Prod 1	42.06	Municipal
3	Rancho Canada	71.56	Municipal

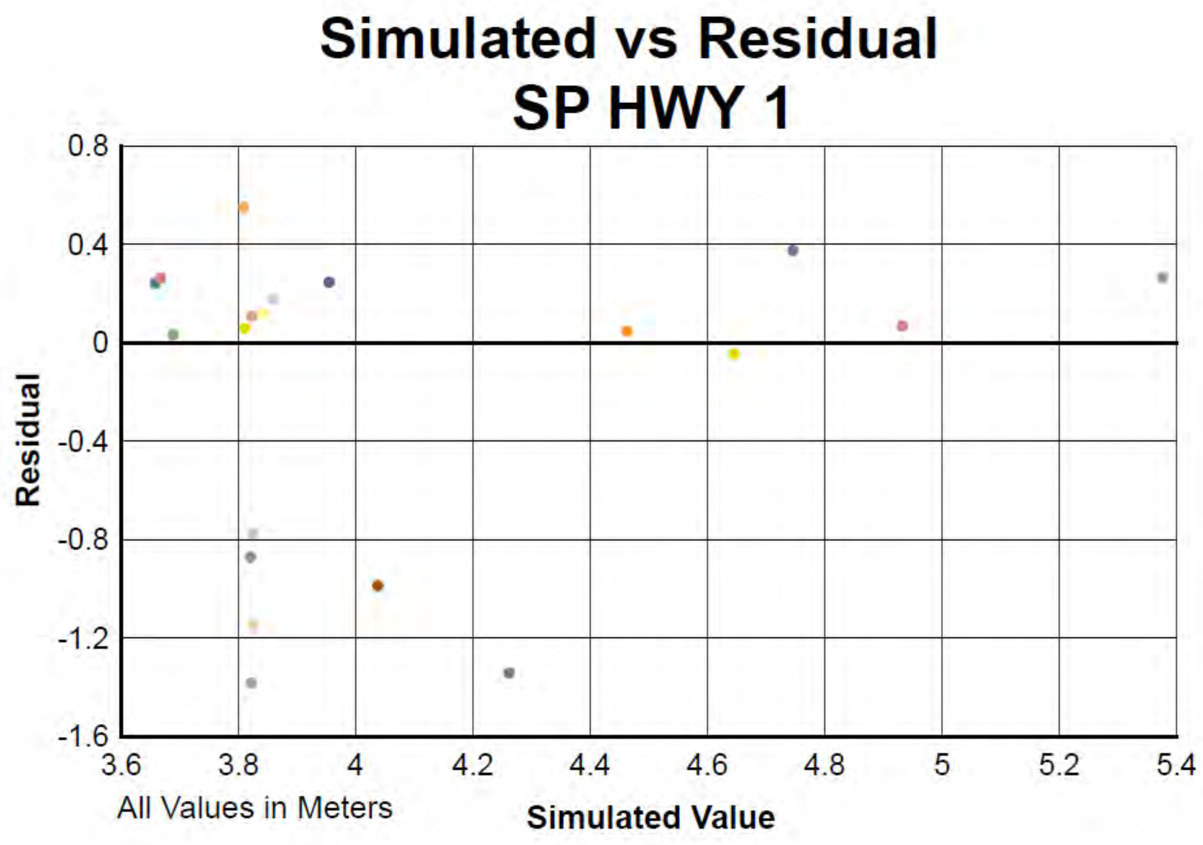
Root Mean Square Error by Well Tier

- Tier 1 – RMSE Average 2.22 with a Standard Deviation of 0.89
- Tier 2 – RMSE Average 6.16 with a Standard Deviation of 1.59
- Tier 3 – RMSE Average 22.36 with a Standard Deviation of 15.84

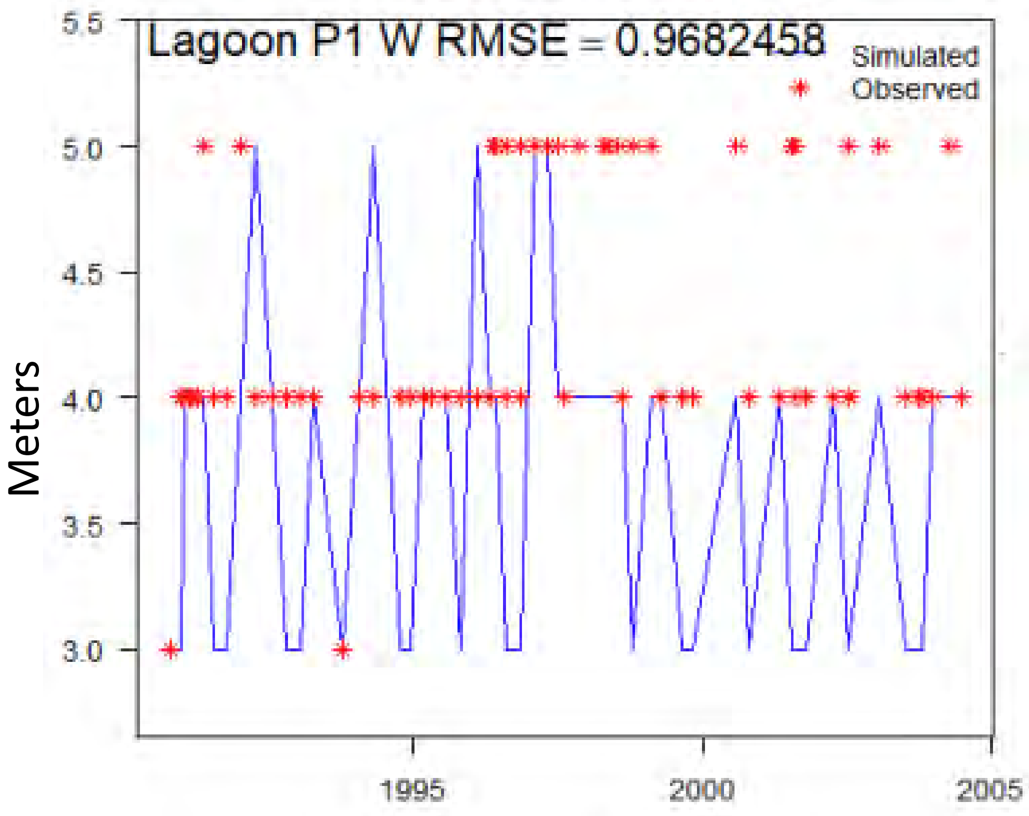
Tier 1 Wells

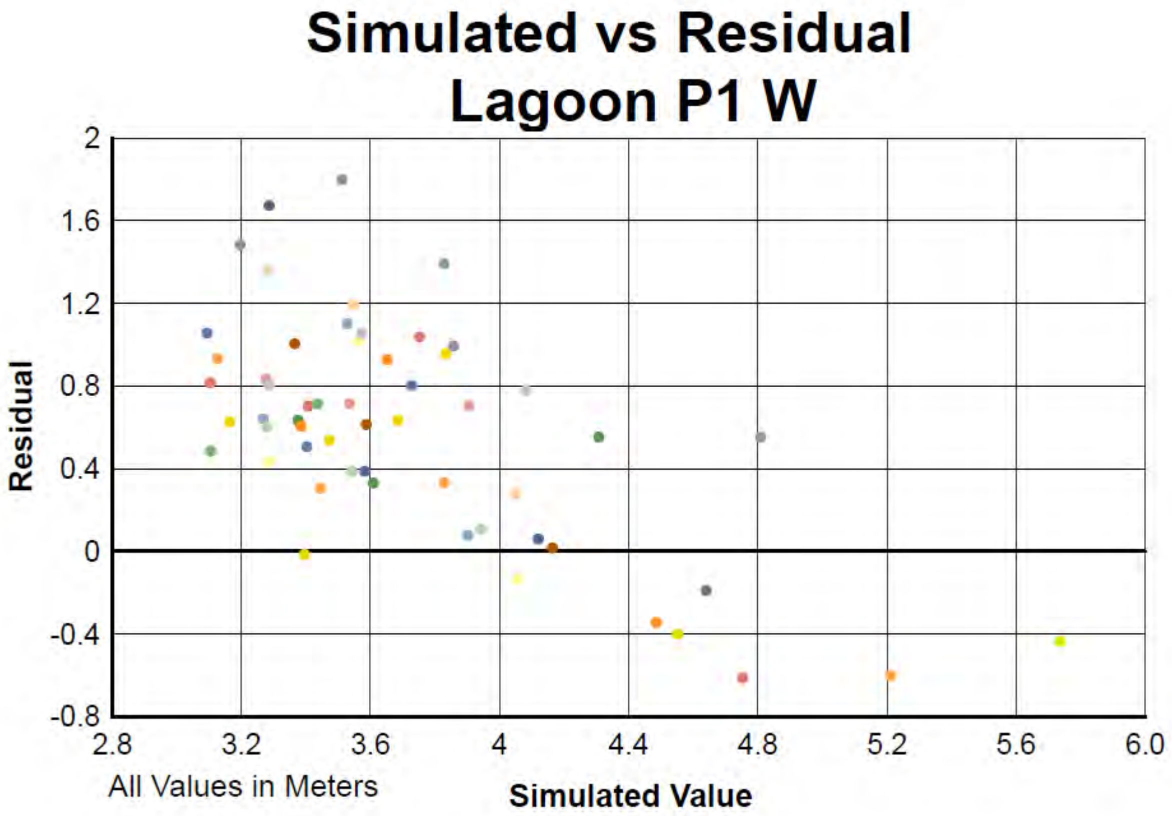


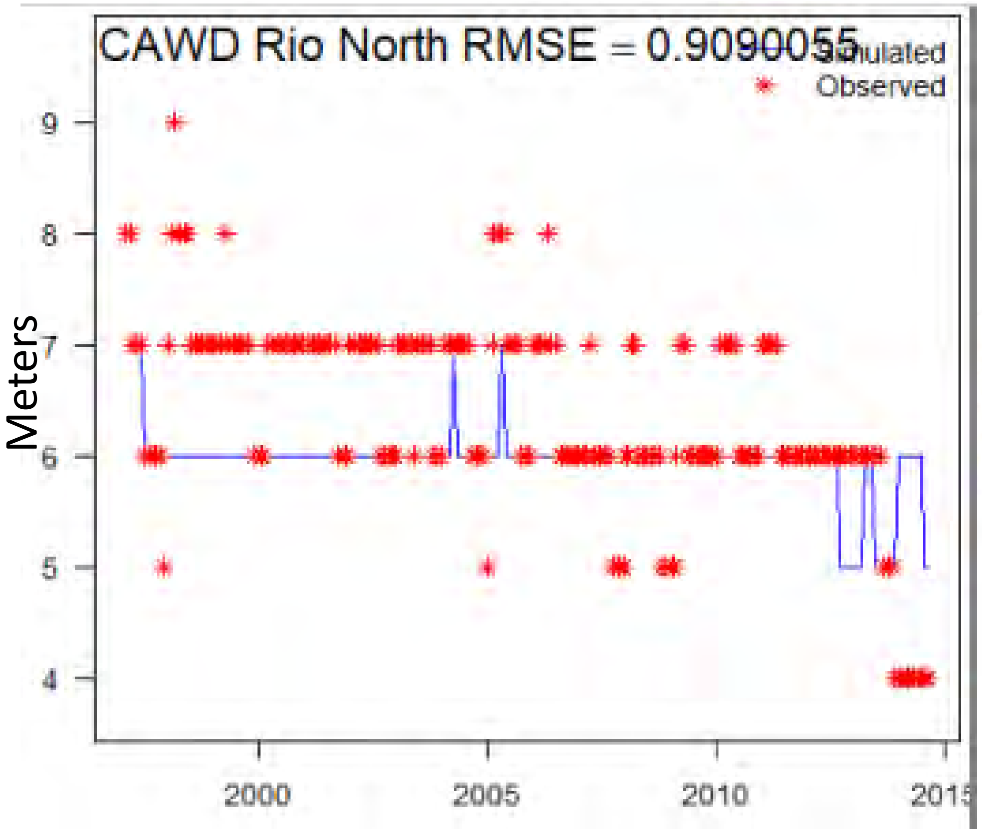
SP HWY 1 RMSE = 0.9499679
Simulated
Observed
Meters
6
5
4
3
2
1991
1992
1993



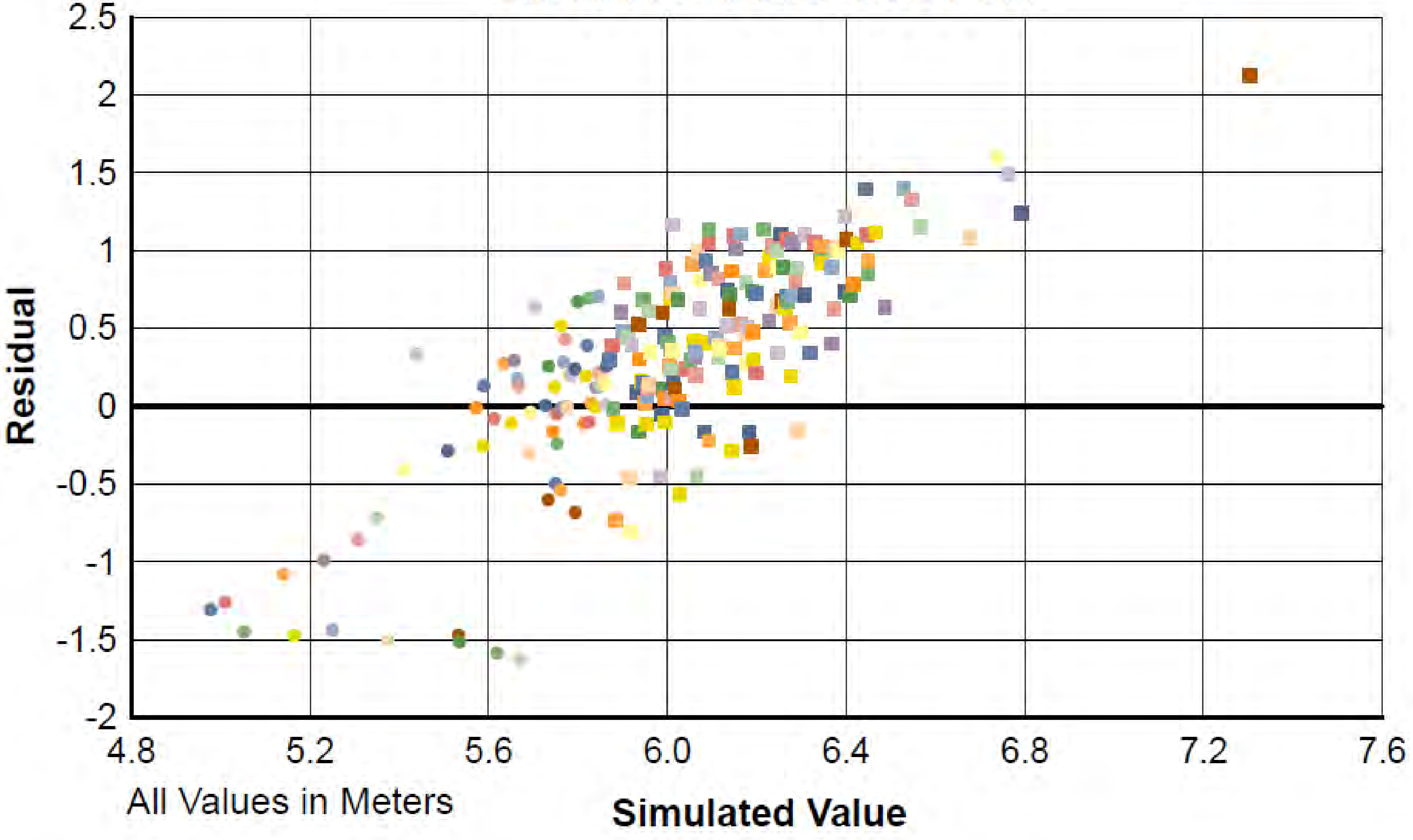
Simulated vs Residual
SP HWY 1
Residual
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
5.4
All Values in Meters
Simulated Value

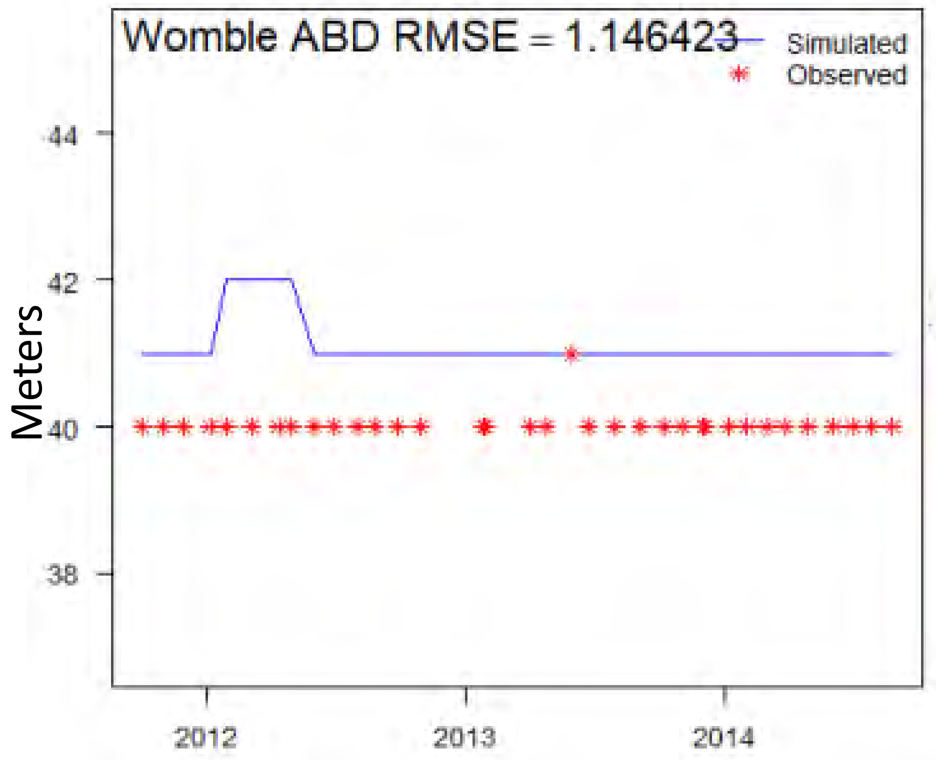

Lagoon P1 W RMSE = 0.9682458
Simulated
Observed
Meters
5.5
5.0
4.5
4.0
3.5
3.0
1995
2000
2005


Simulated vs Residual
Lagoon P1 W
Residual
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
2.8
3.2
3.6
4
4.4
4.8
5.2
5.6
6.0
All Values in Meters
Simulated Value

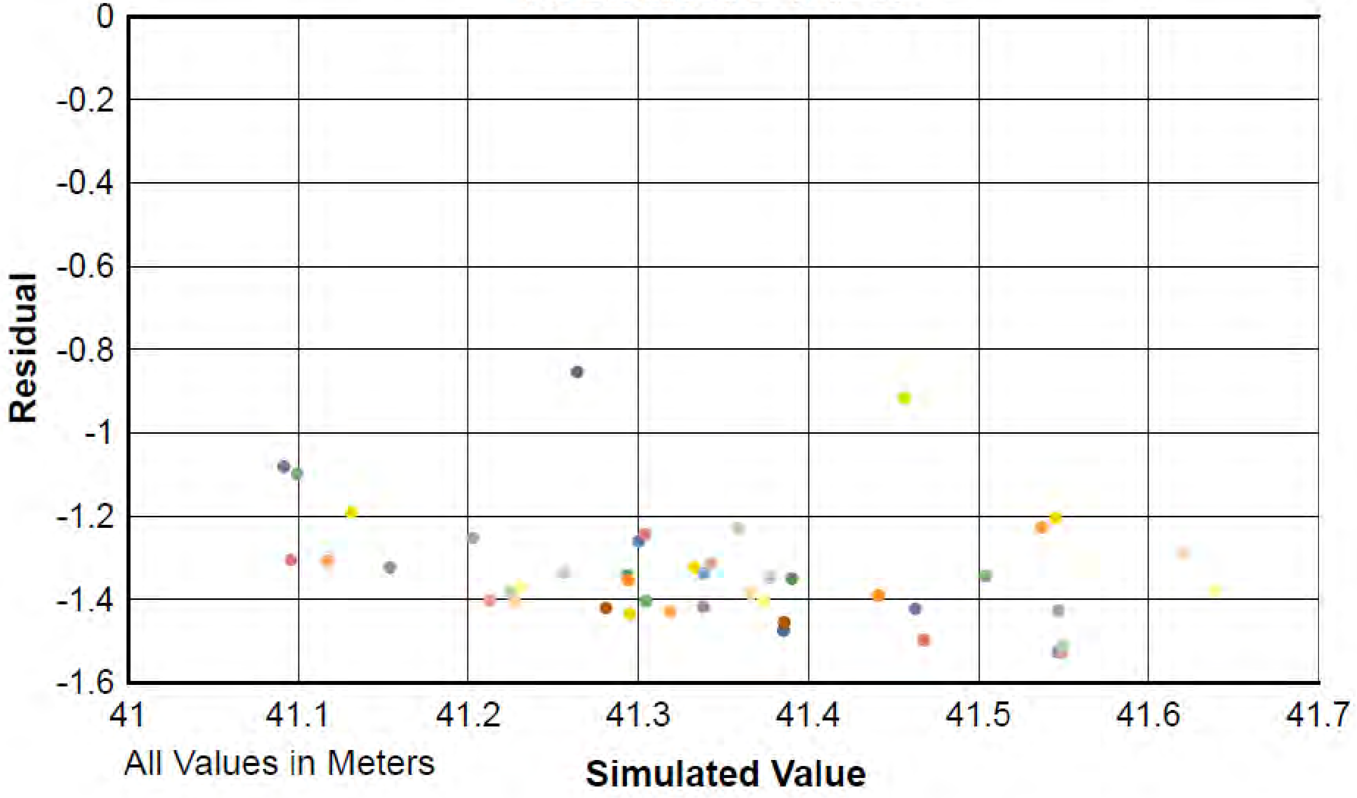


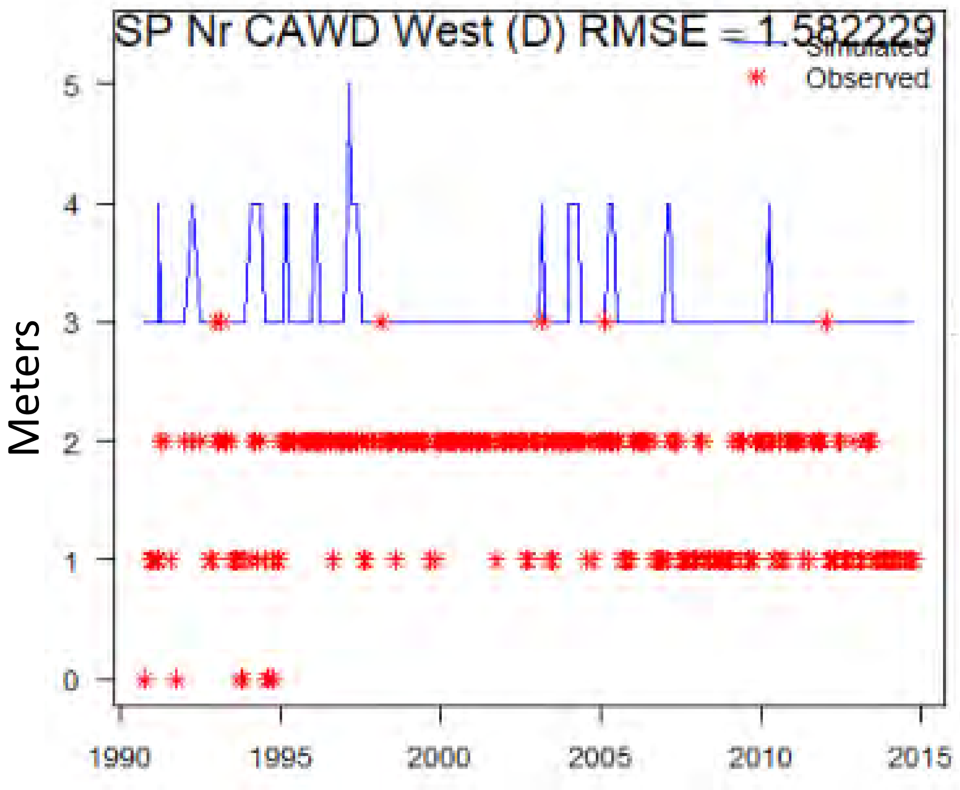
Simulated vs Residual CAWD Rio North



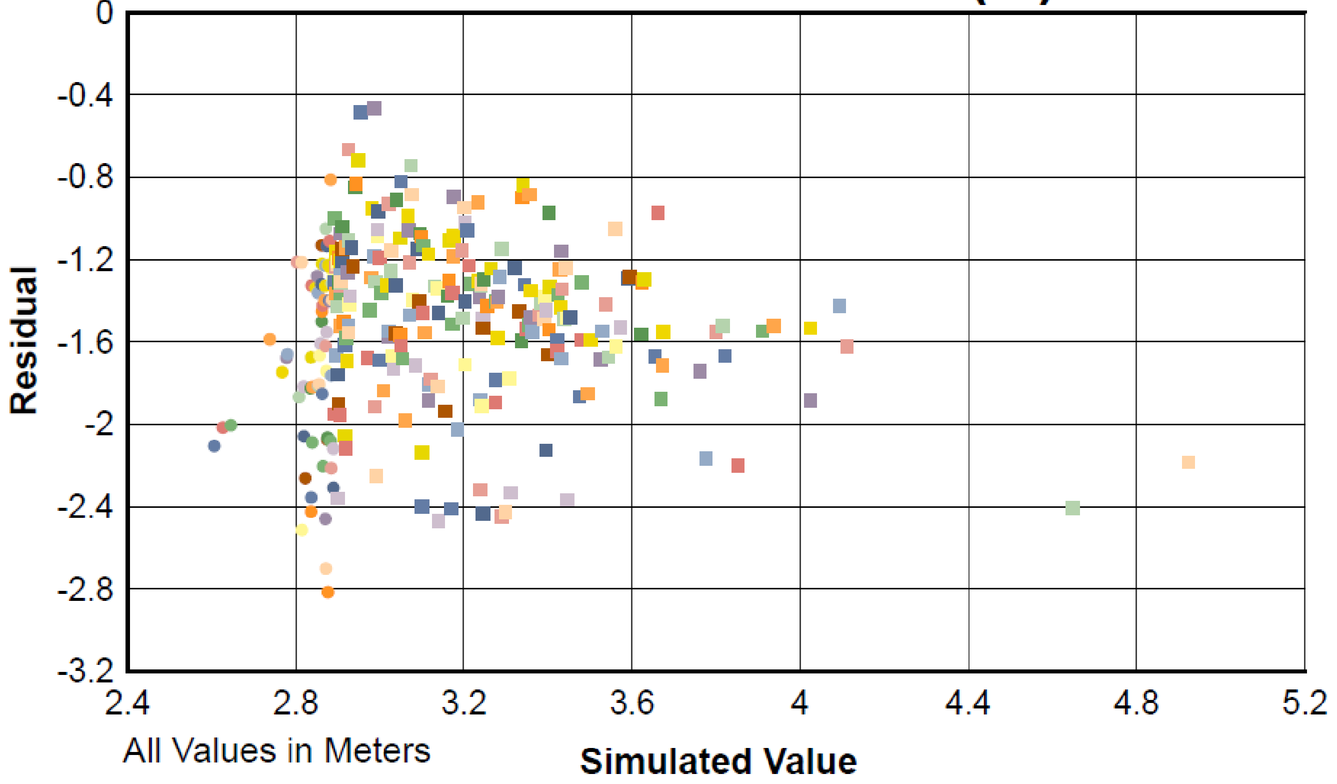


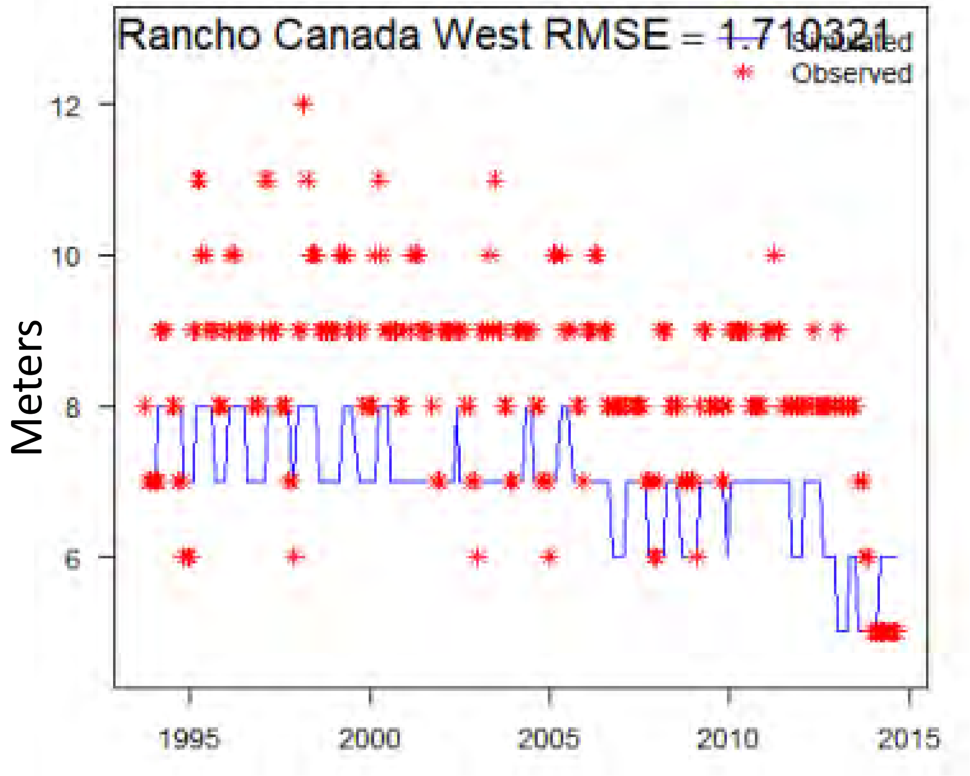
Simulated vs Residual Womble ABD



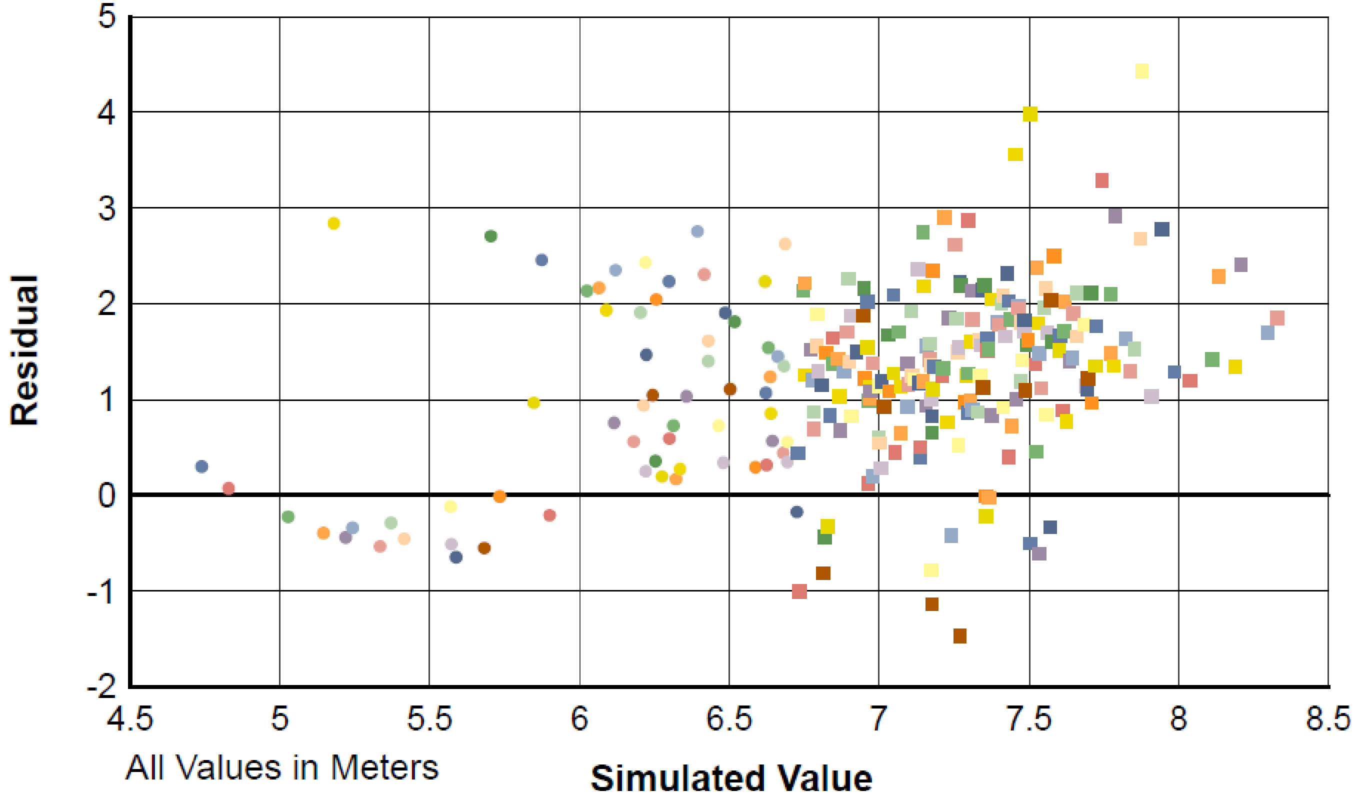


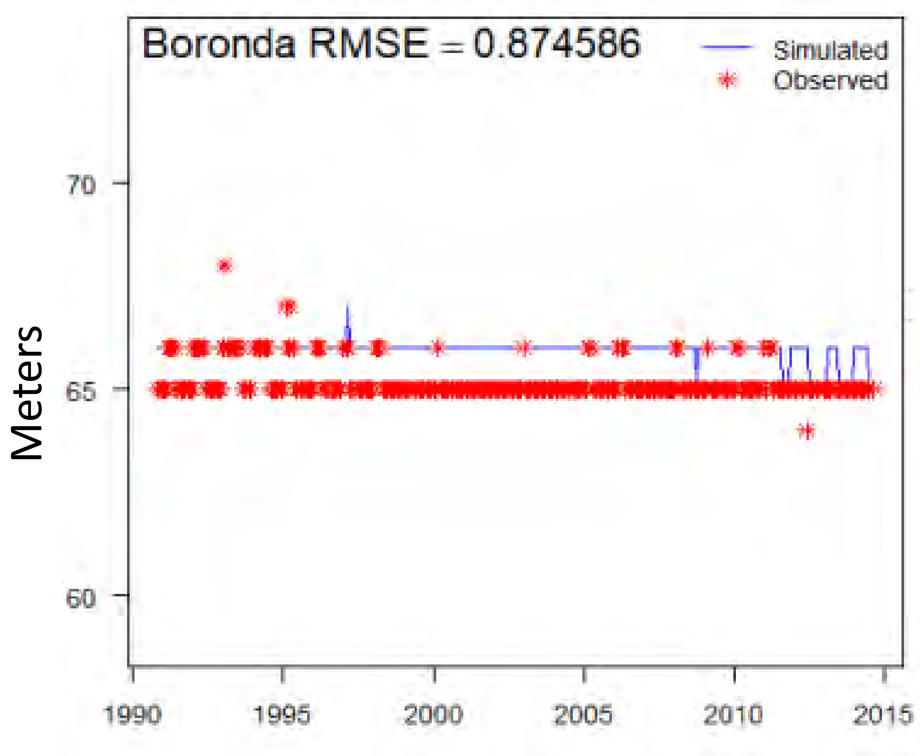
Simulated vs Residual SP Nr CAWD West (D)

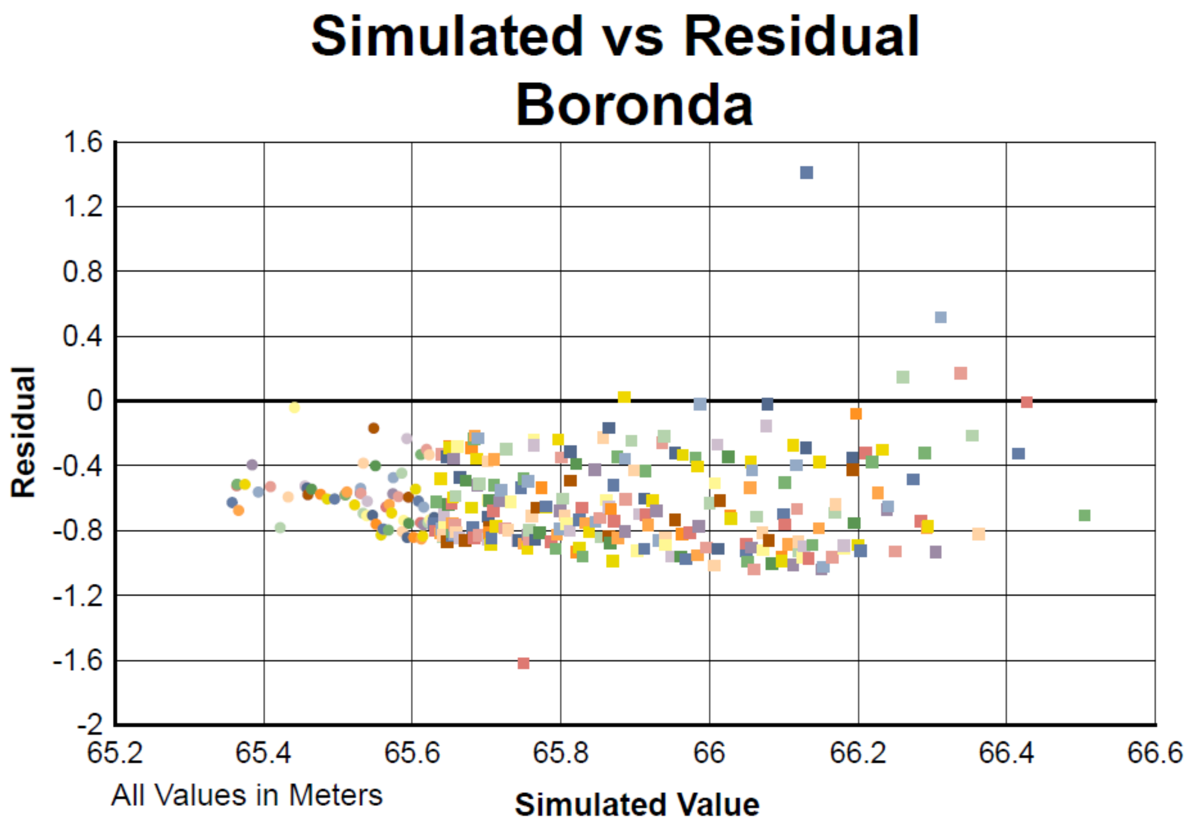


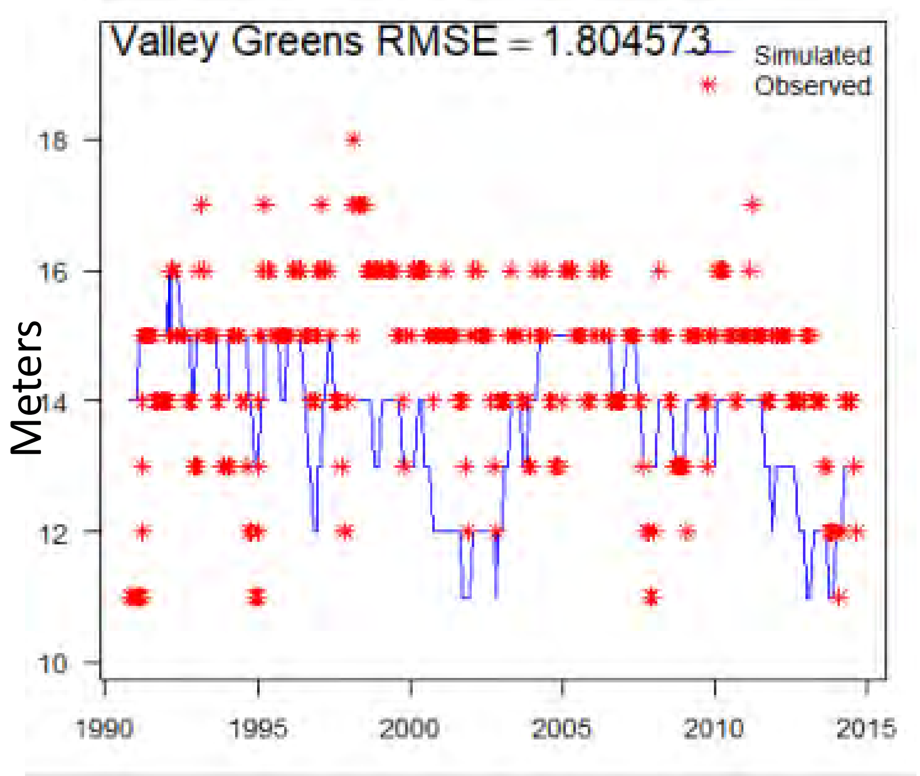


Simulated vs Residual Rancho Canada West

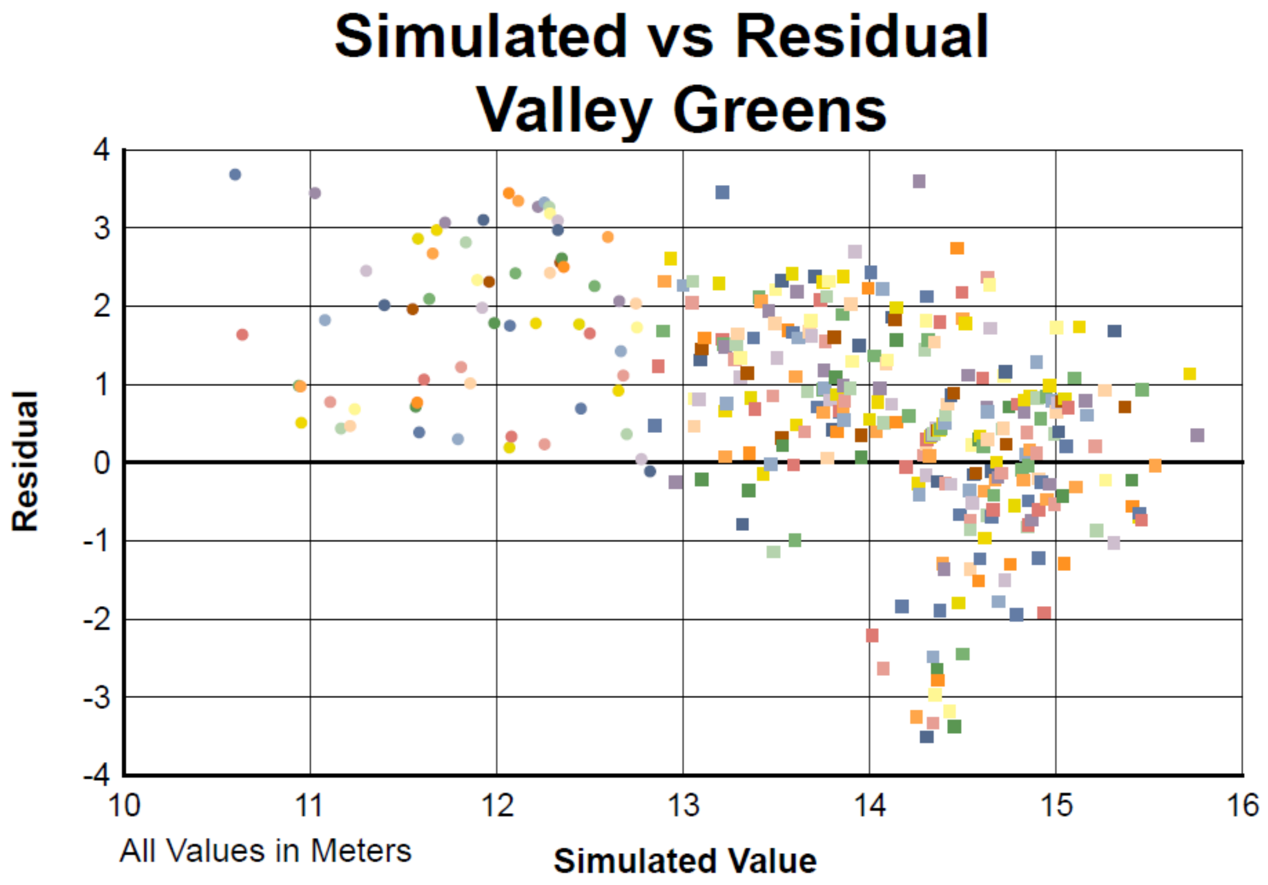



Boronda RMSE = 0.874586
Simulated
Observed
Meters
70
65
60
1990
1995
2000
2005
2010
2015

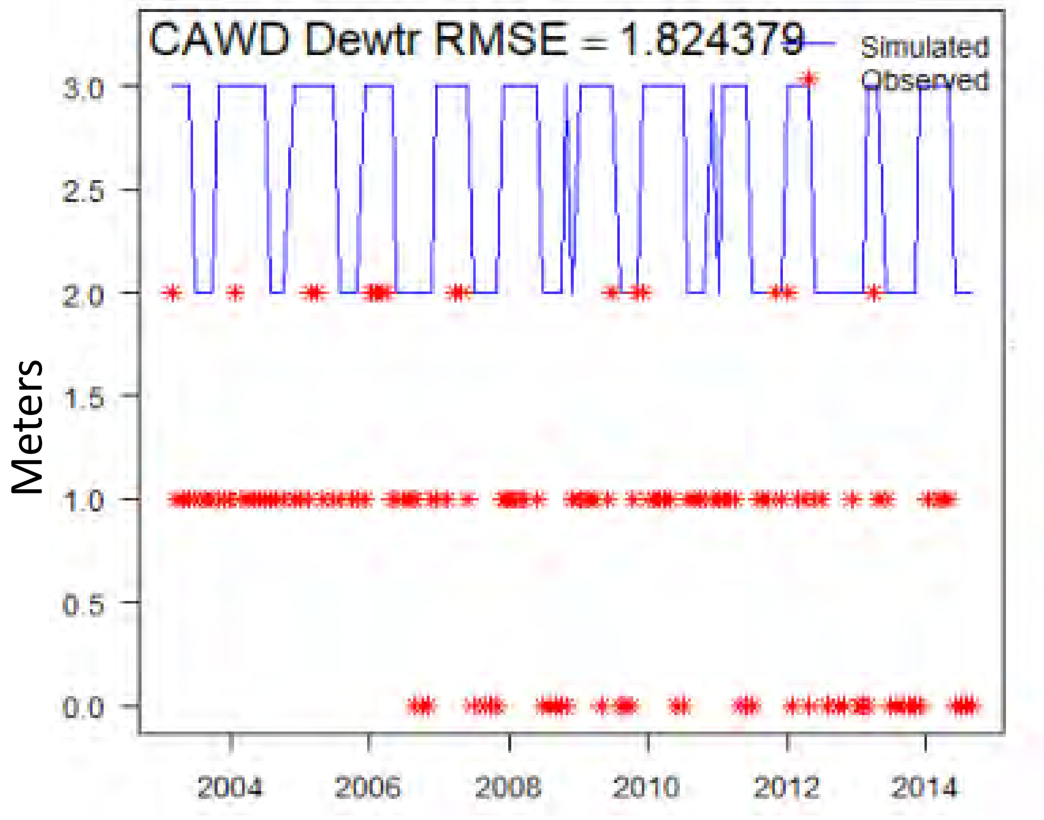

Simulated vs Residual
Boronda
Residual
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
65.2
65.4
65.6
65.8
66
66.2
66.4
66.6
All Values in Meters
Simulated Value

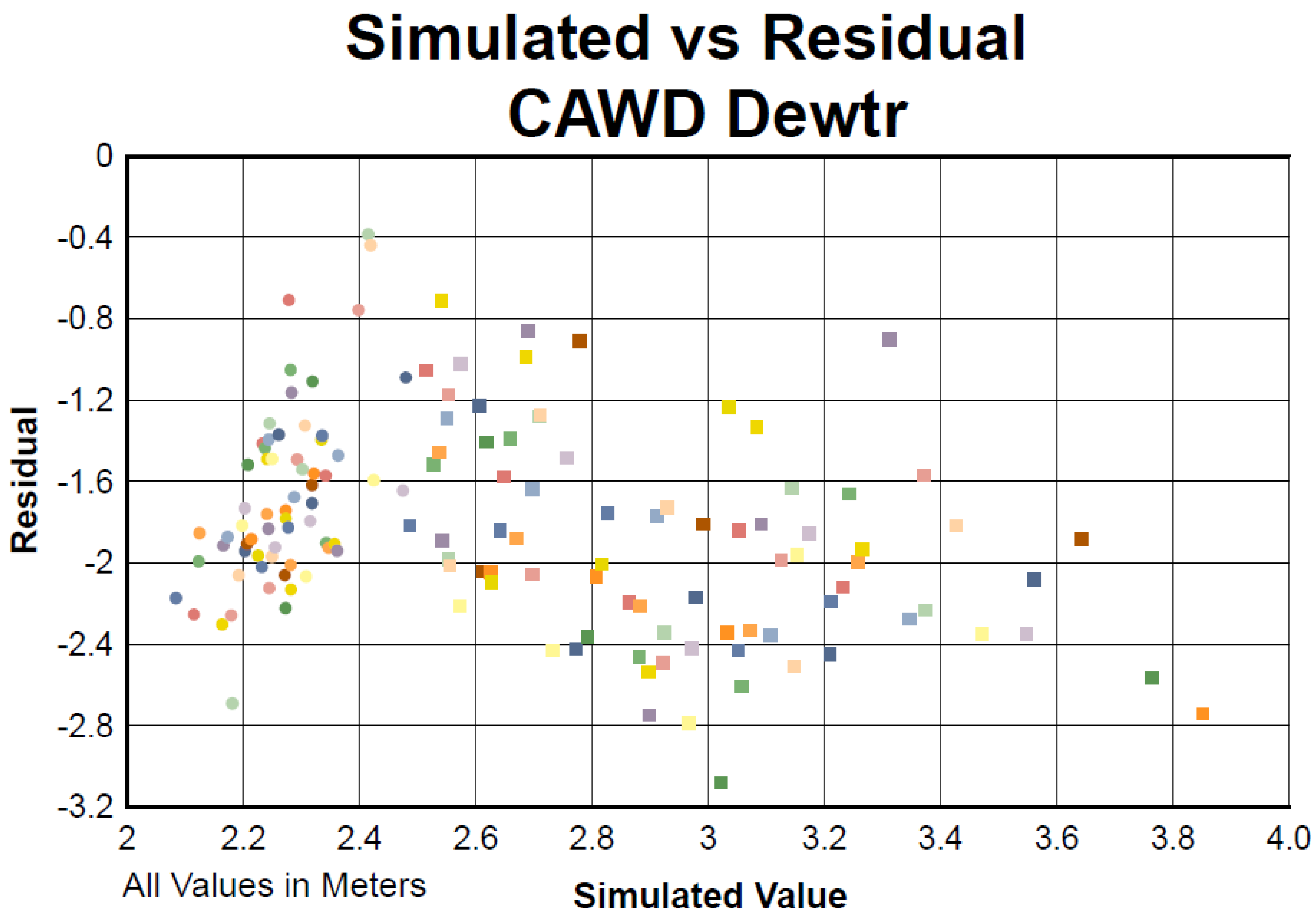


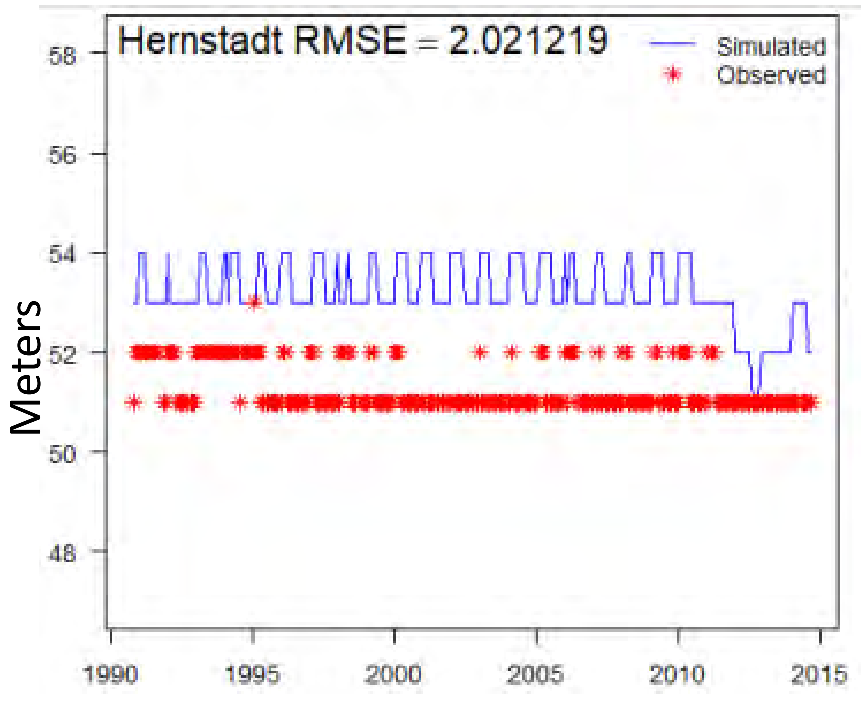
Valley Greens RMSE = 1.804573
Simulated
Observed
Meters
18
16
14
12
10
1990
1995
2000
2005
2010
2015

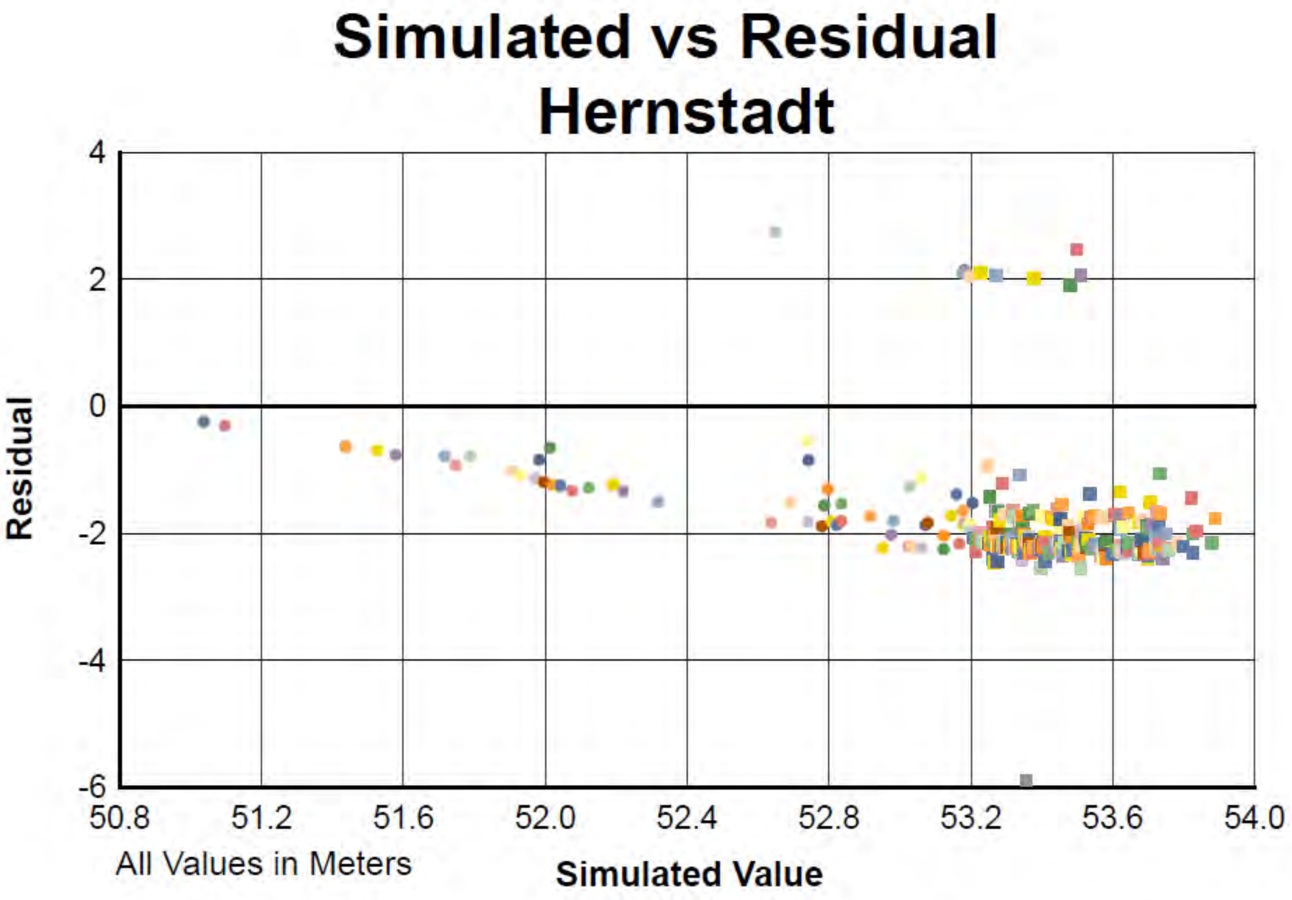


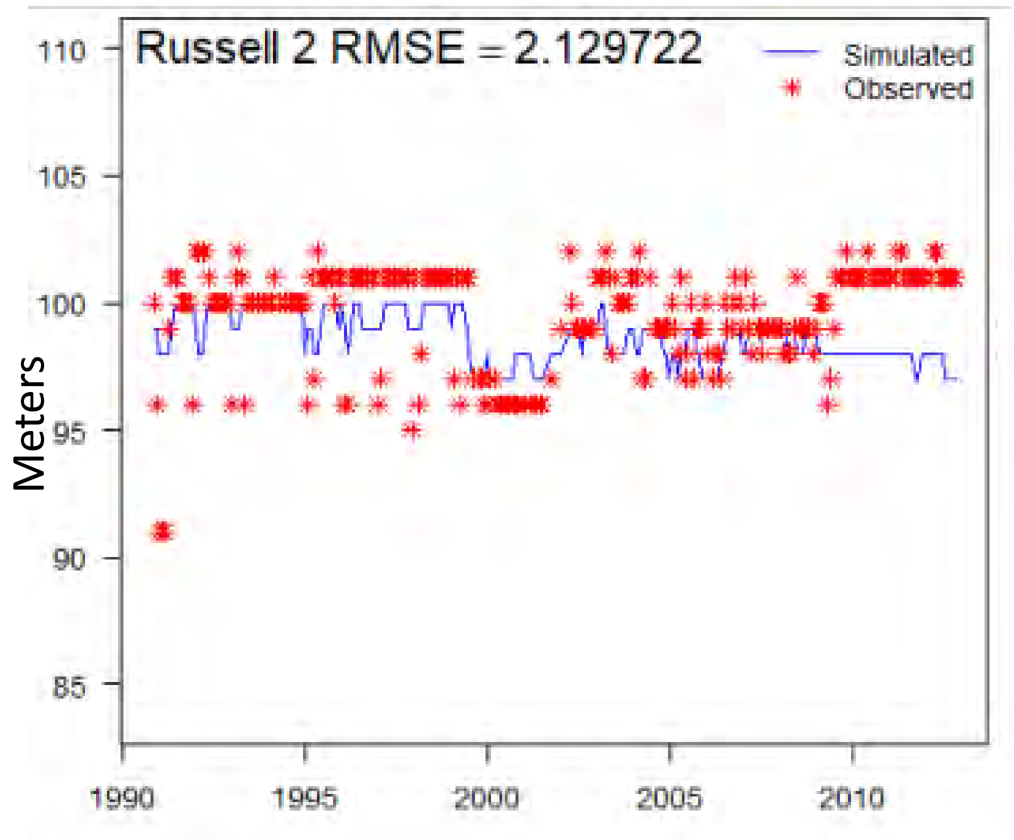
Simulated vs Residual
Valley Greens
Residual
4
3
2
1
0
-1
-2
-3
-4
10
11
12
13
14
15
16
All Values in Meters
Simulated Value


CAWD Dewtr RMSE = 1.824379
Simulated
Observed
Meters
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2004
2006
2008
2010
2012
2014

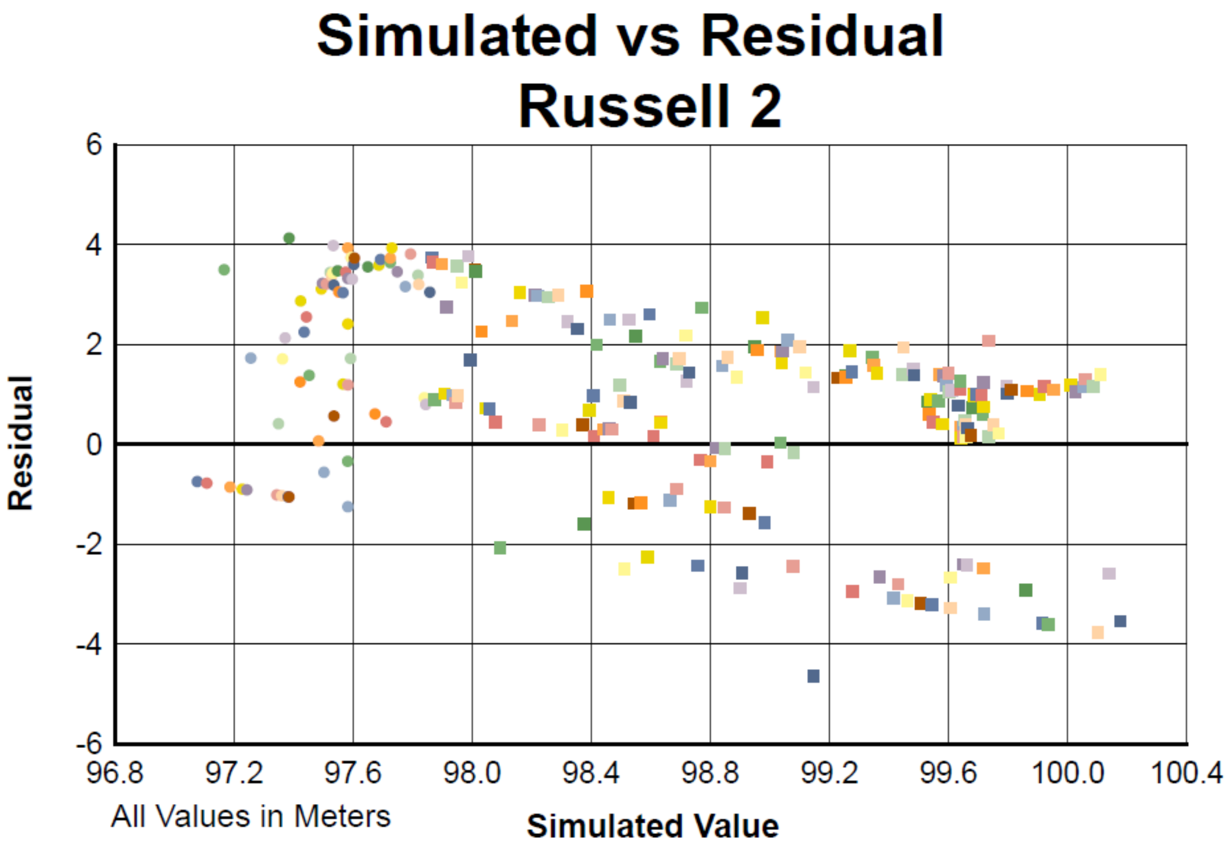

Simulated vs Residual
CAWD Dewtr
Residual
0
-0.4
-0.8
-1.2
-1.6
-2
-2.4
-2.8
-3.2
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4.0
All Values in Meters
Simulated Value


Hernstadt RMSE = 2.021219
Simulated
Observed
Meters
58
56
54
52
50
48
1990
1995
2000
2005
2010
2015

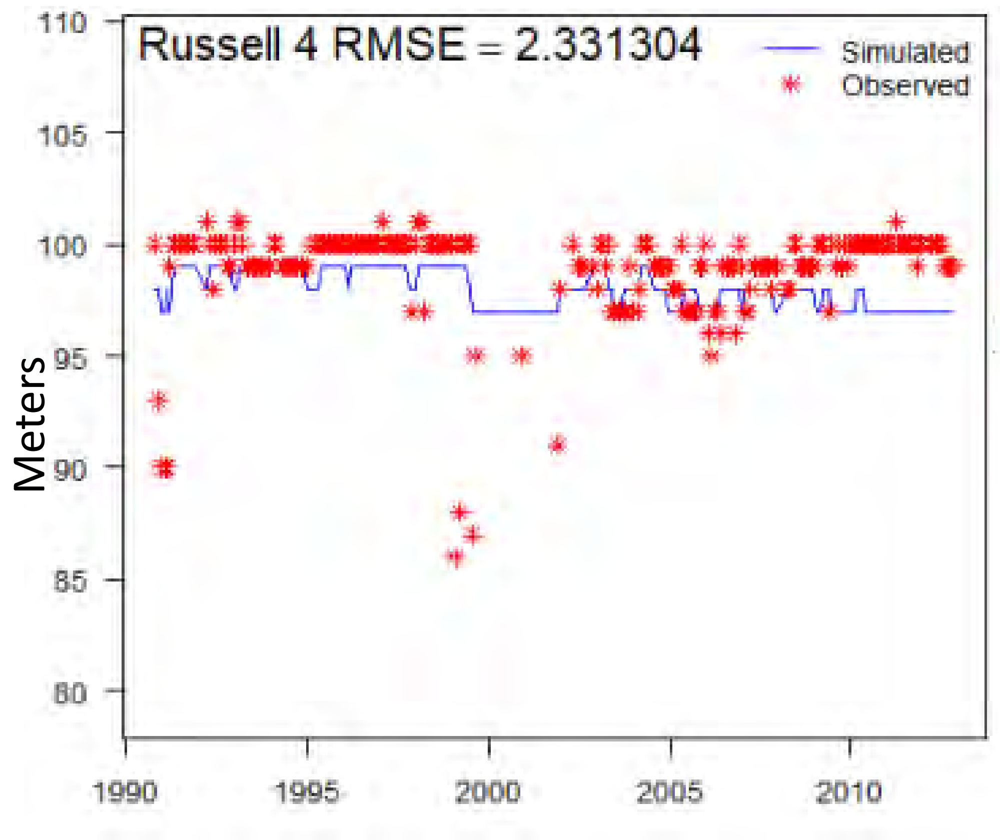

Simulated vs Residual
Hernstadt
Residual
4
2
0
-2
-4
-6
50.8
51.2
51.6
52.0
52.4
52.8
53.2
53.6
54.0
All Values in Meters
Simulated Value



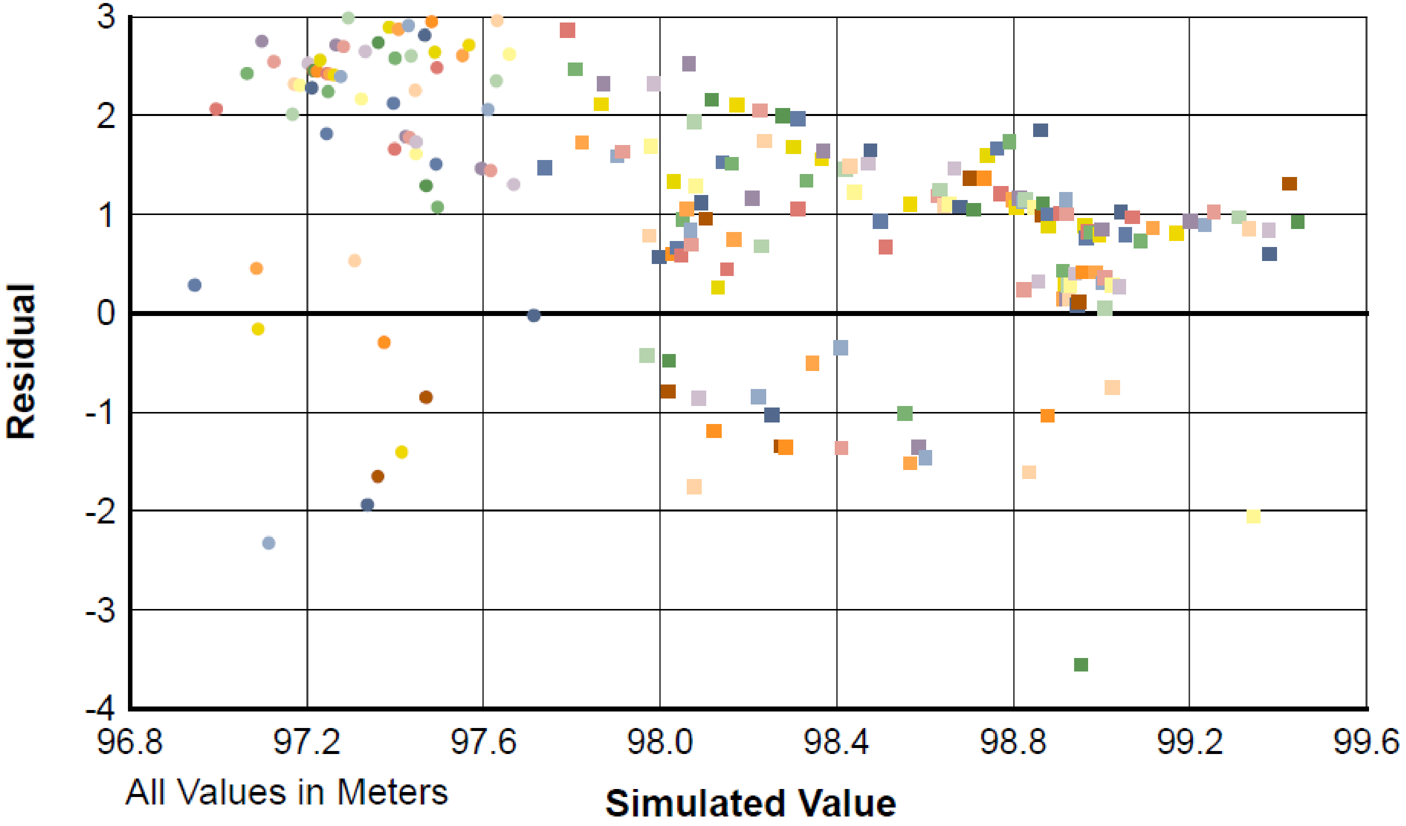
Russell 2 RMSE = 2.129722
Simulated
Observed
Meters
110
105
100
95
90
85
1990
1995
2000
2005
2010

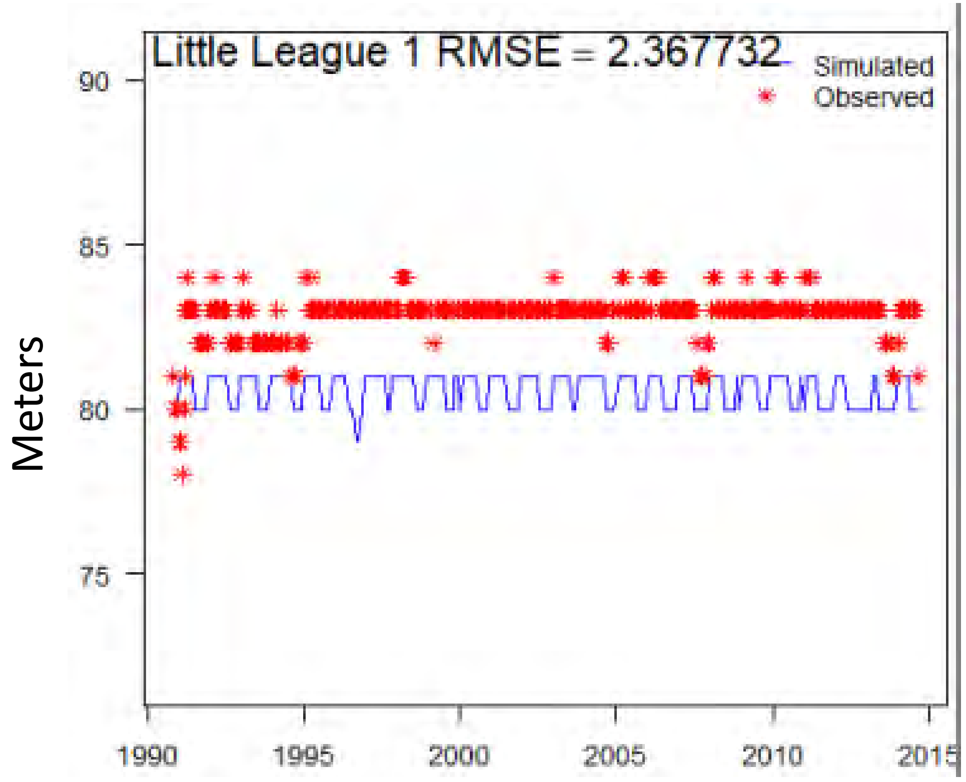


Simulated vs Residual
Russell 2
Residual
6
4
2
0
-2
-4
-6
96.8
97.2
97.6
98.0
98.4
98.8
99.2
99.6
100.0
100.4
All Values in Meters
Simulated Value

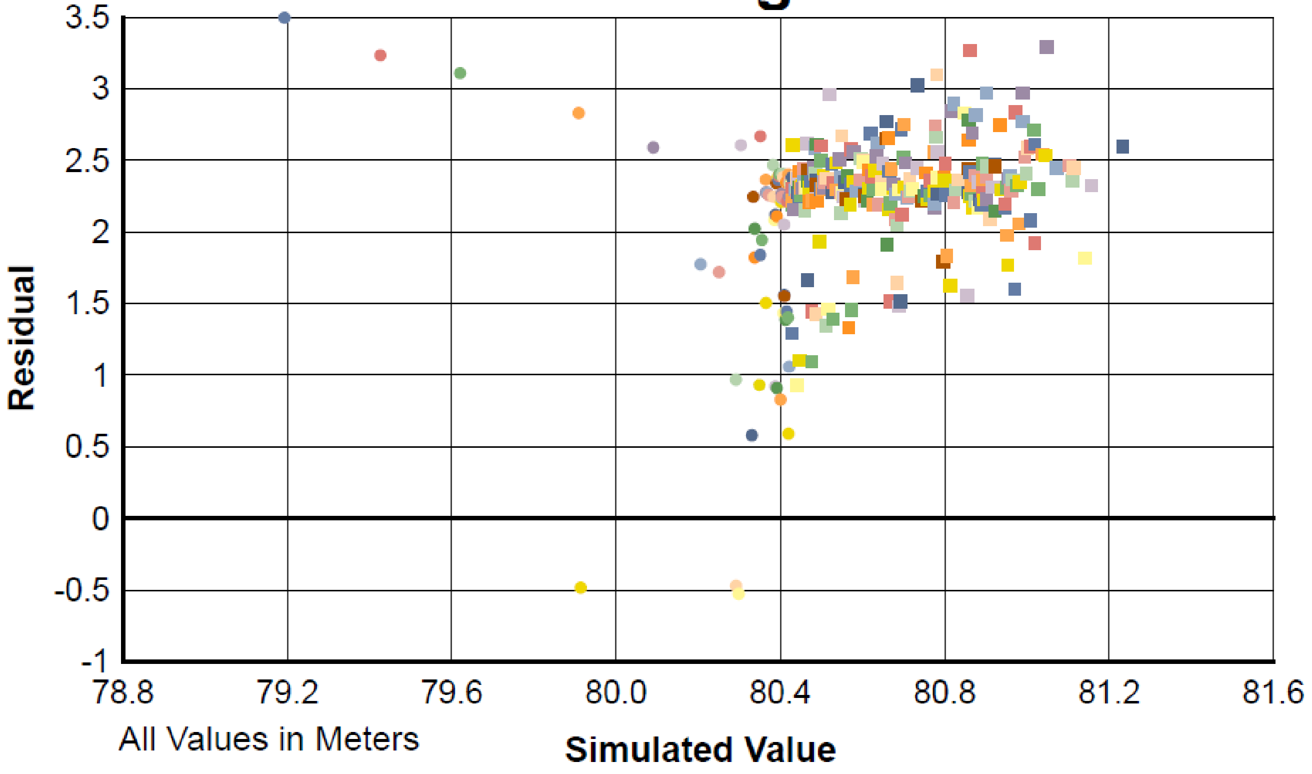


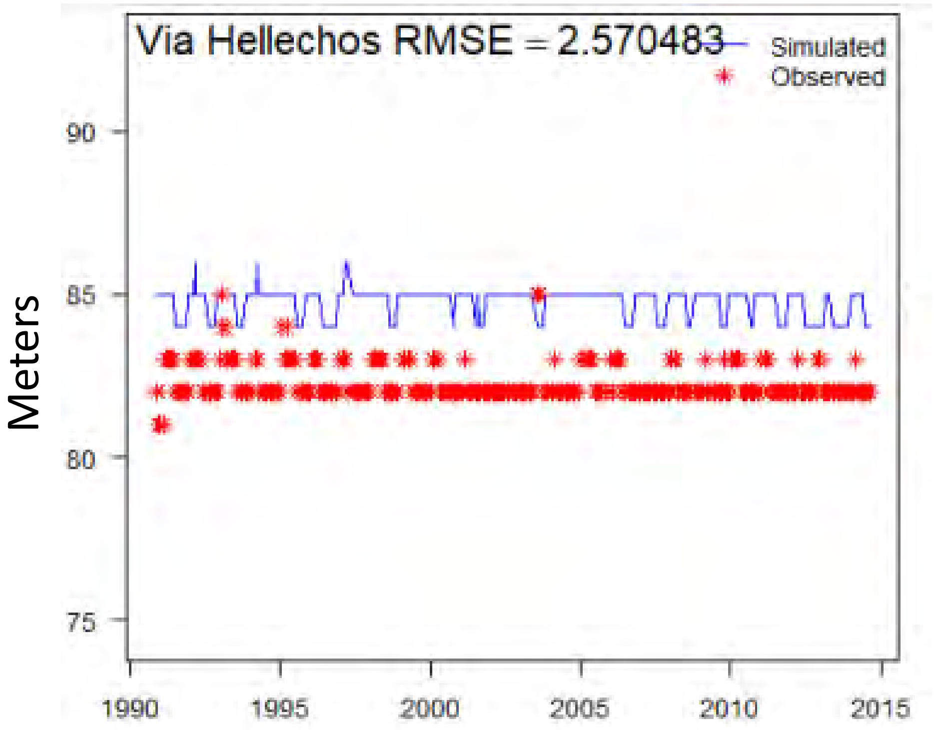
Simulated vs Residual Russell 4



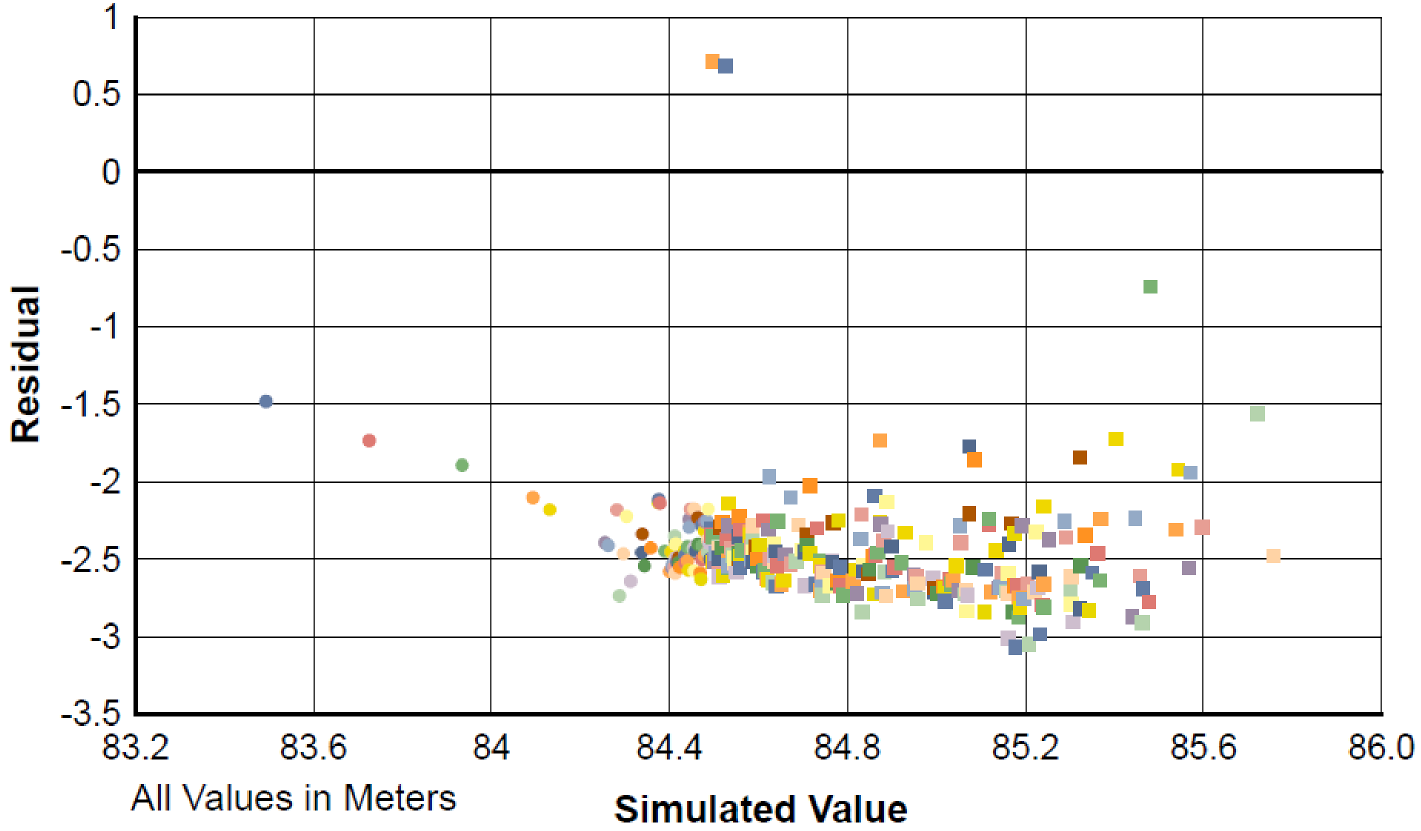


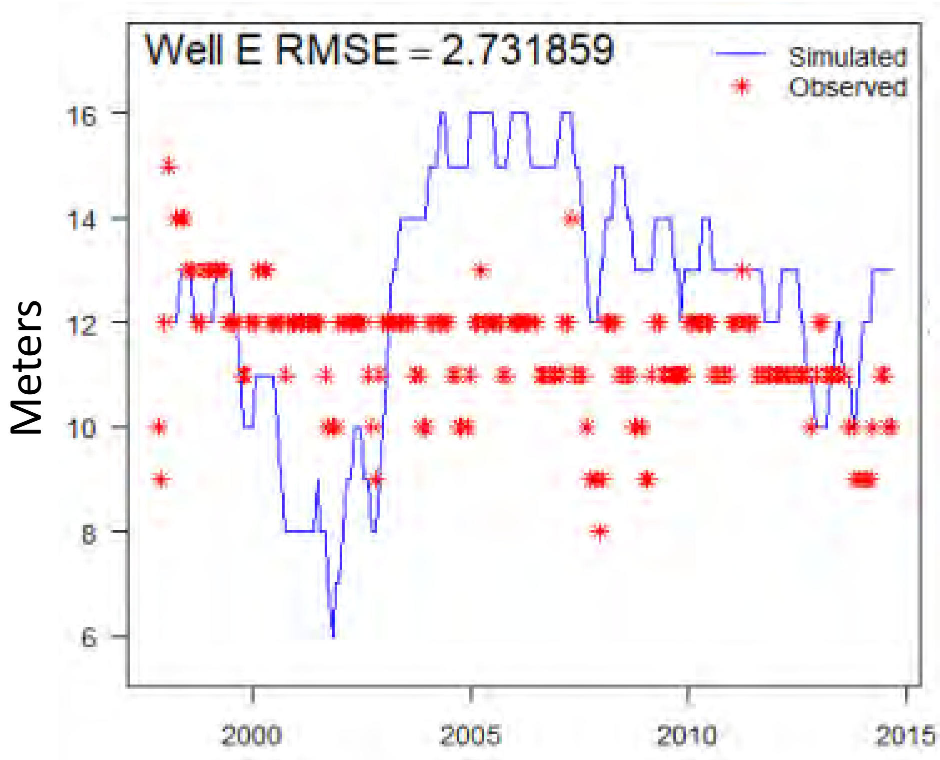
Simulated vs Residual
Little League 1

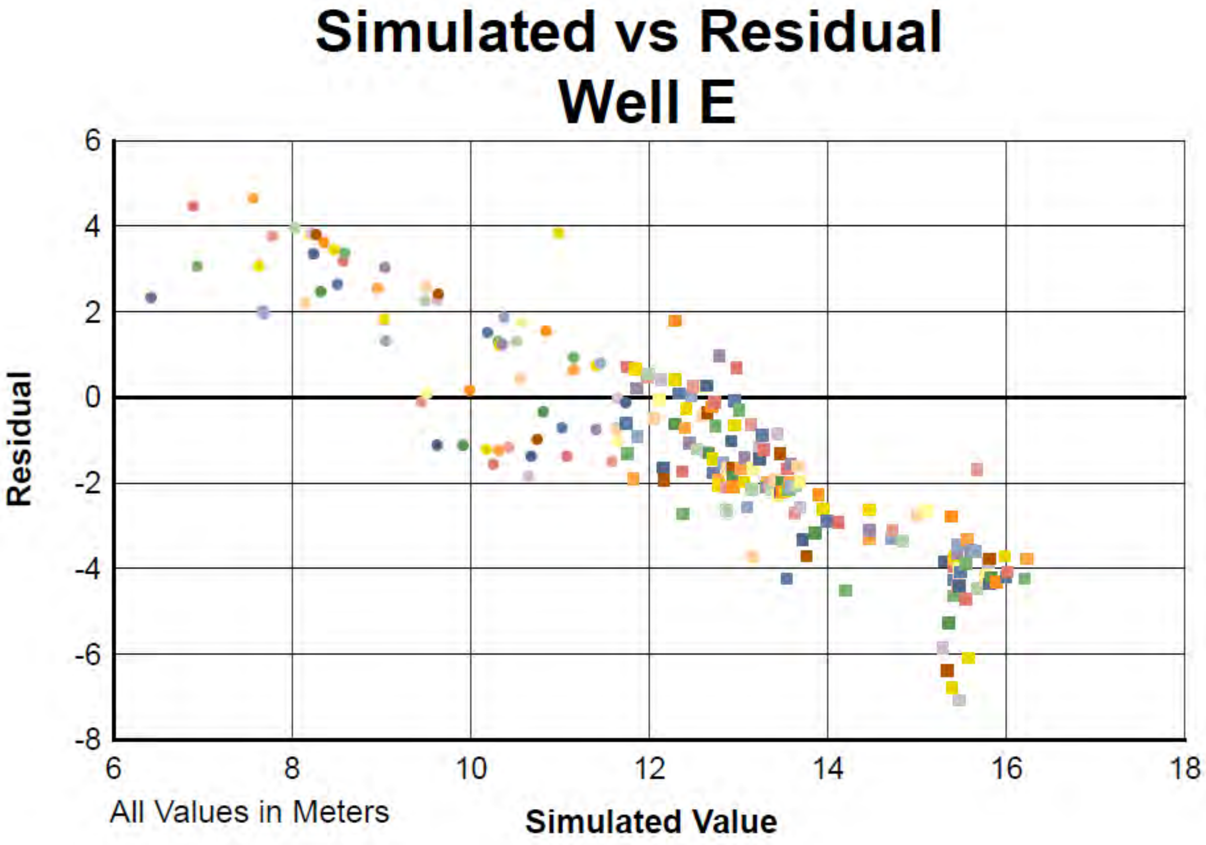


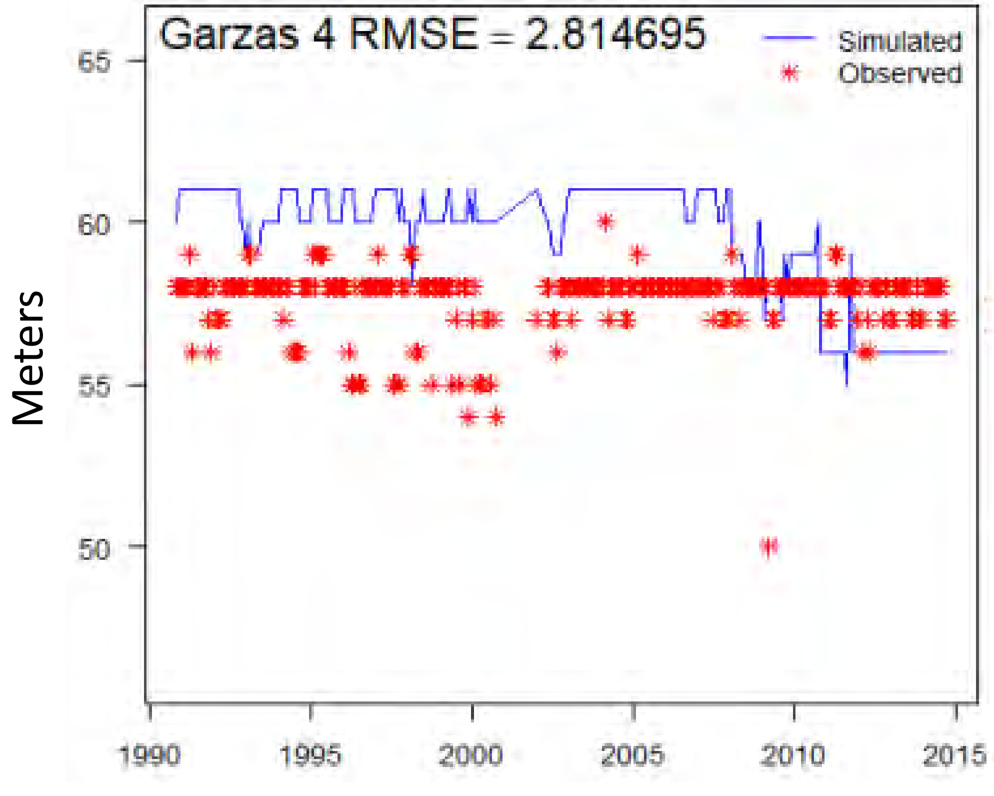


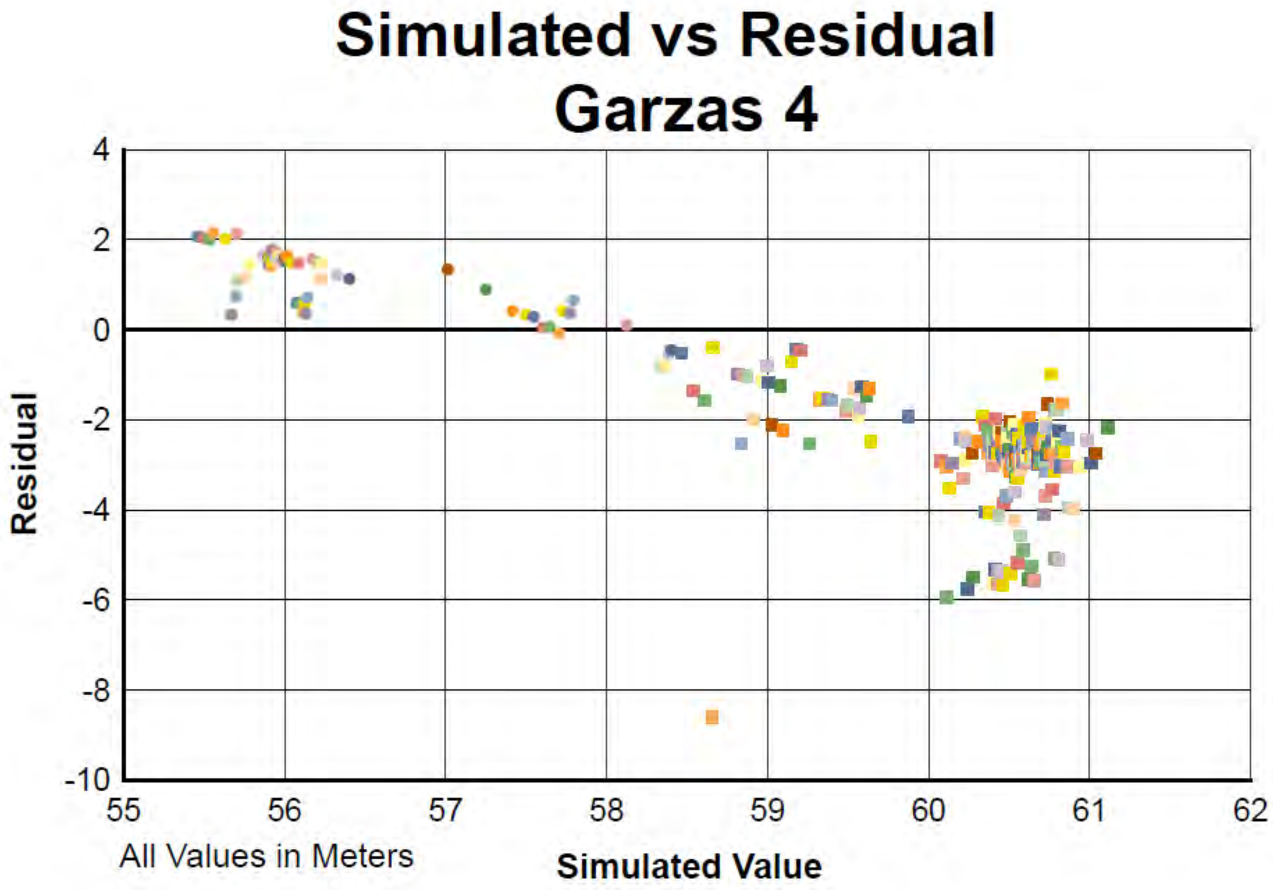
Simulated vs Residual Via Hellechos

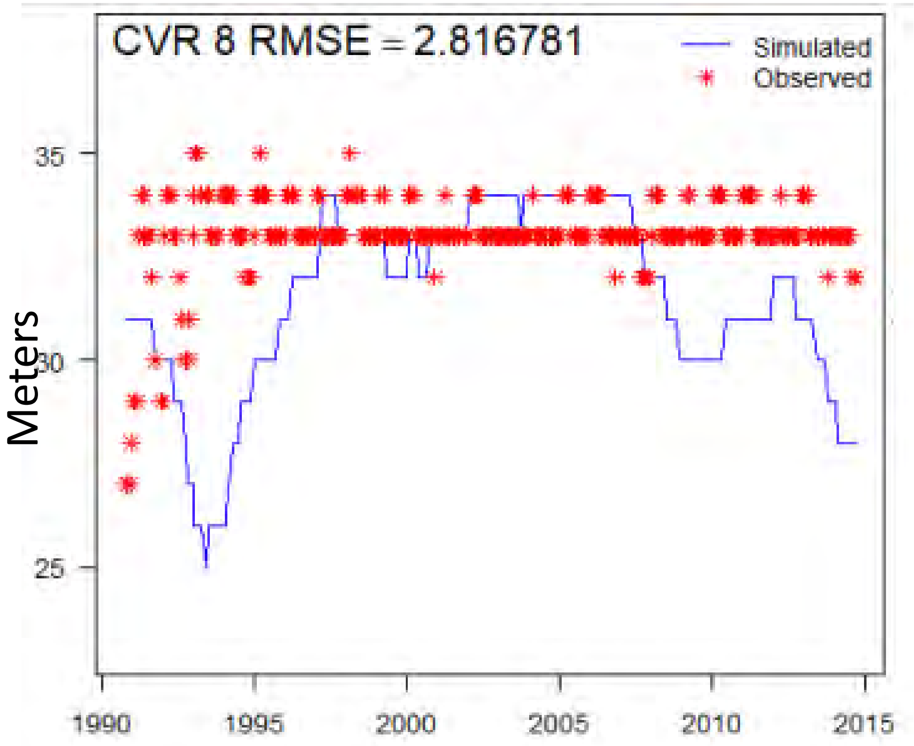



Well E RMSE = 2.731859
Simulated
Observed
Meters
16
14
12
10
8
6
2000
2005
2010
2015

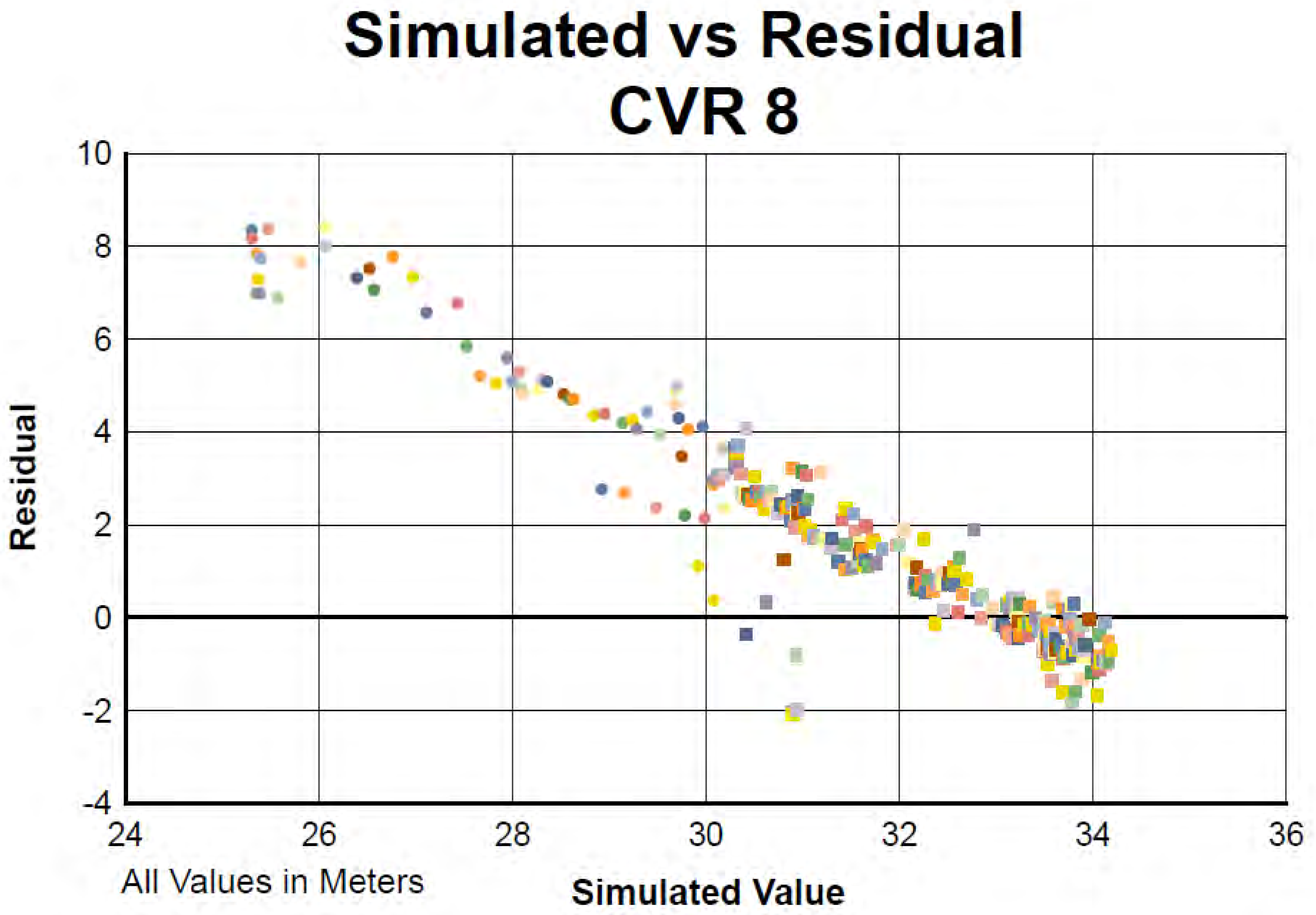

Simulated vs Residual
Well E
Residual
6
4
2
0
-2
-4
-6
-8
6
8
10
12
14
16
18
All Values in Meters
Simulated Value


Garzas 4 RMSE = 2.814695
Simulated
Observed
Meters
65
60
55
50
1990
1995
2000
2005
2010
2015

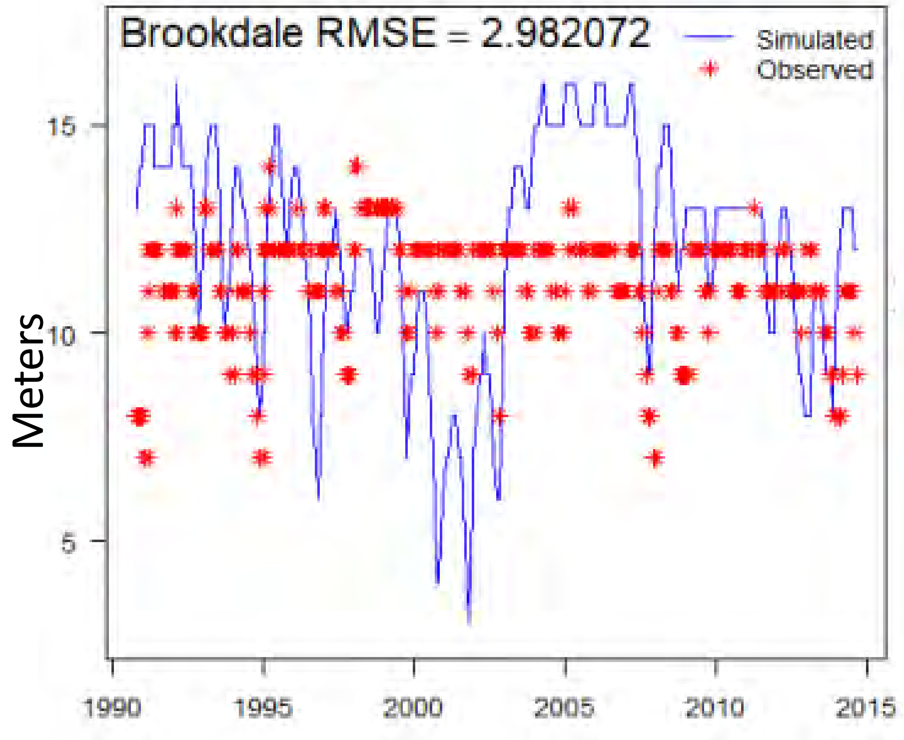

Simulated vs Residual
Garzas 4
Residual
4
2
0
-2
-4
-6
-8
-10
55
56
57
58
59
60
61
62
All Values in Meters
Simulated Value

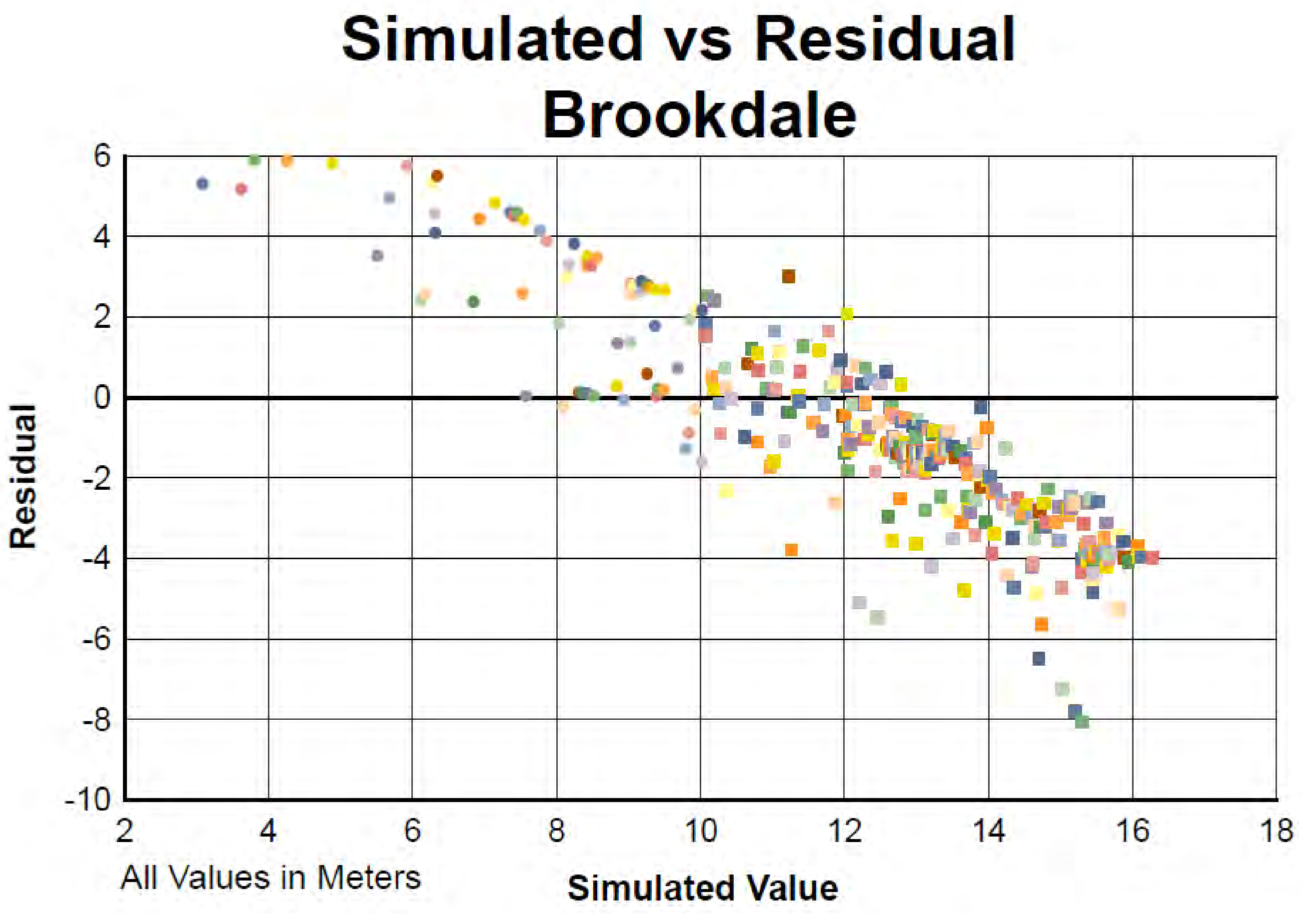


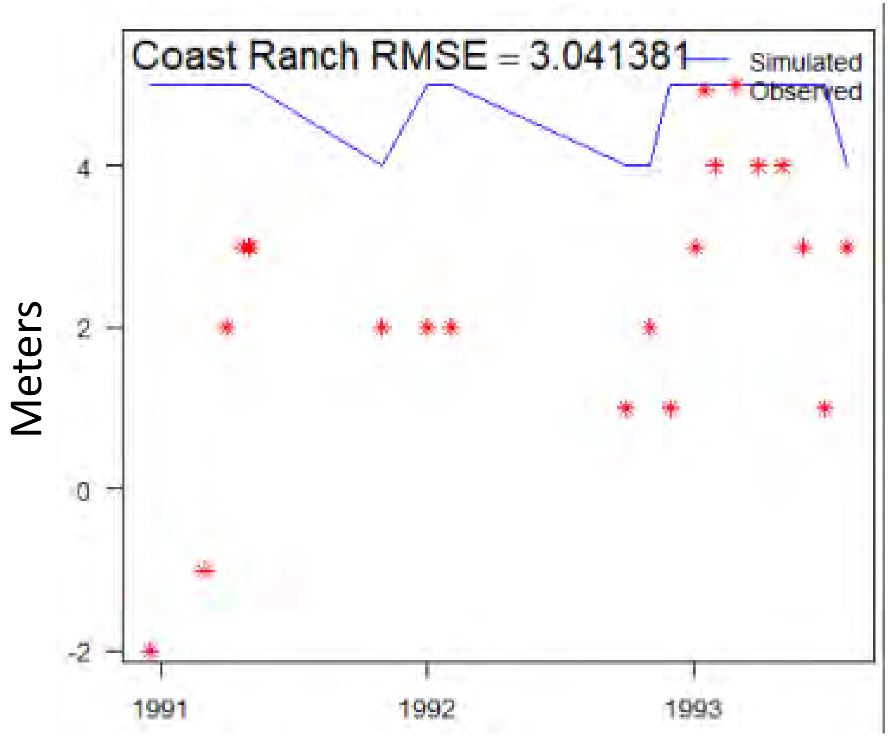
CVR 8 RMSE = 2.816781
Simulated
Observed
Meters
35
30
25
1990
1995
2000
2005
2010
2015

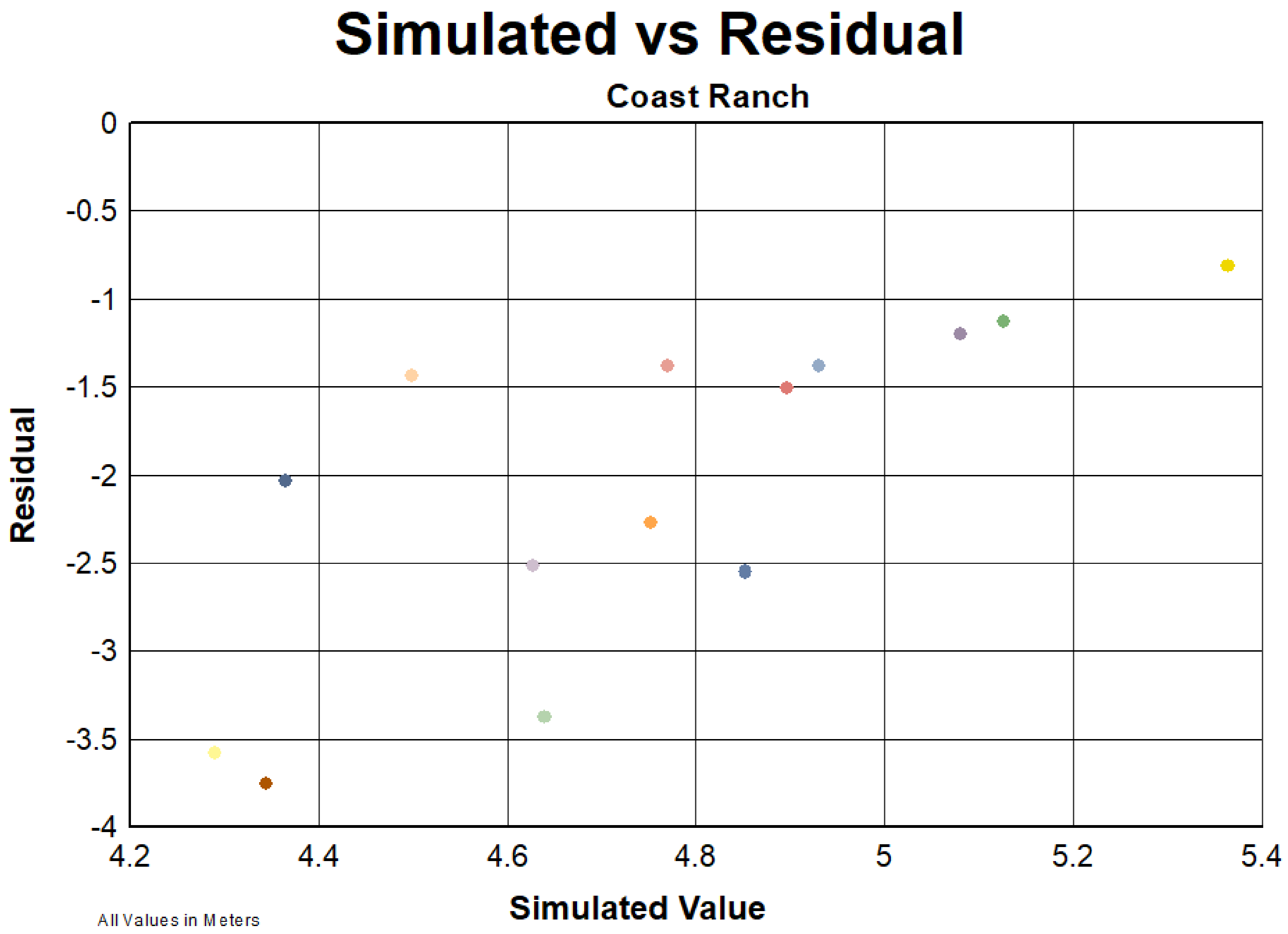


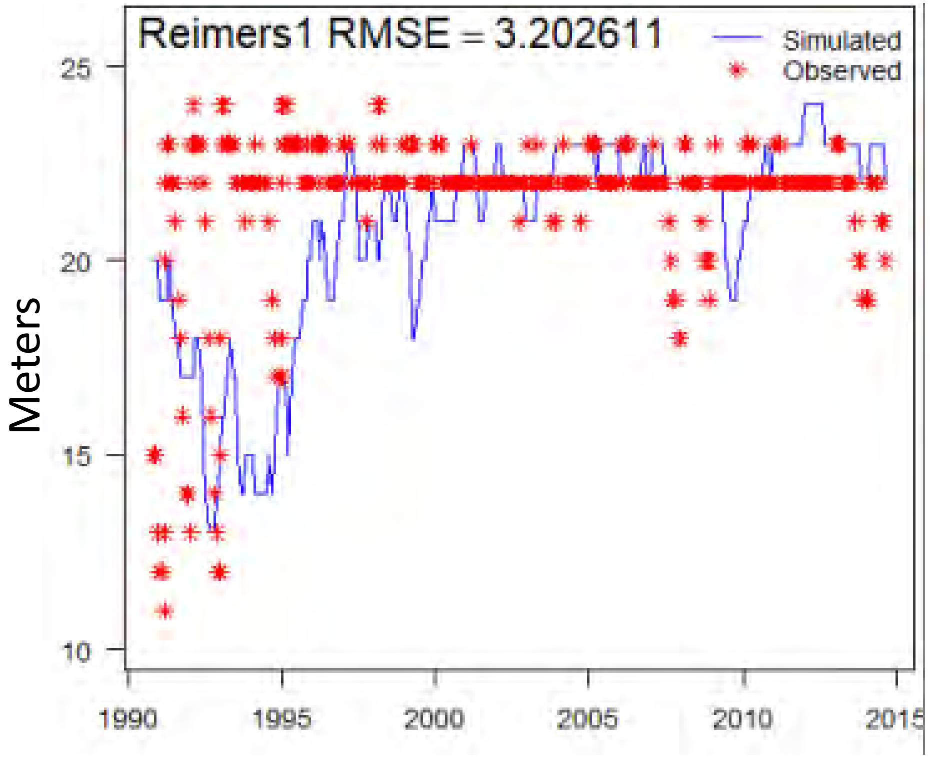
Simulated vs Residual
CVR 8
Residual
10
8
6
4
2
0
-2
-4
24
26
28
30
32
34
36
All Values in Meters
Simulated Value

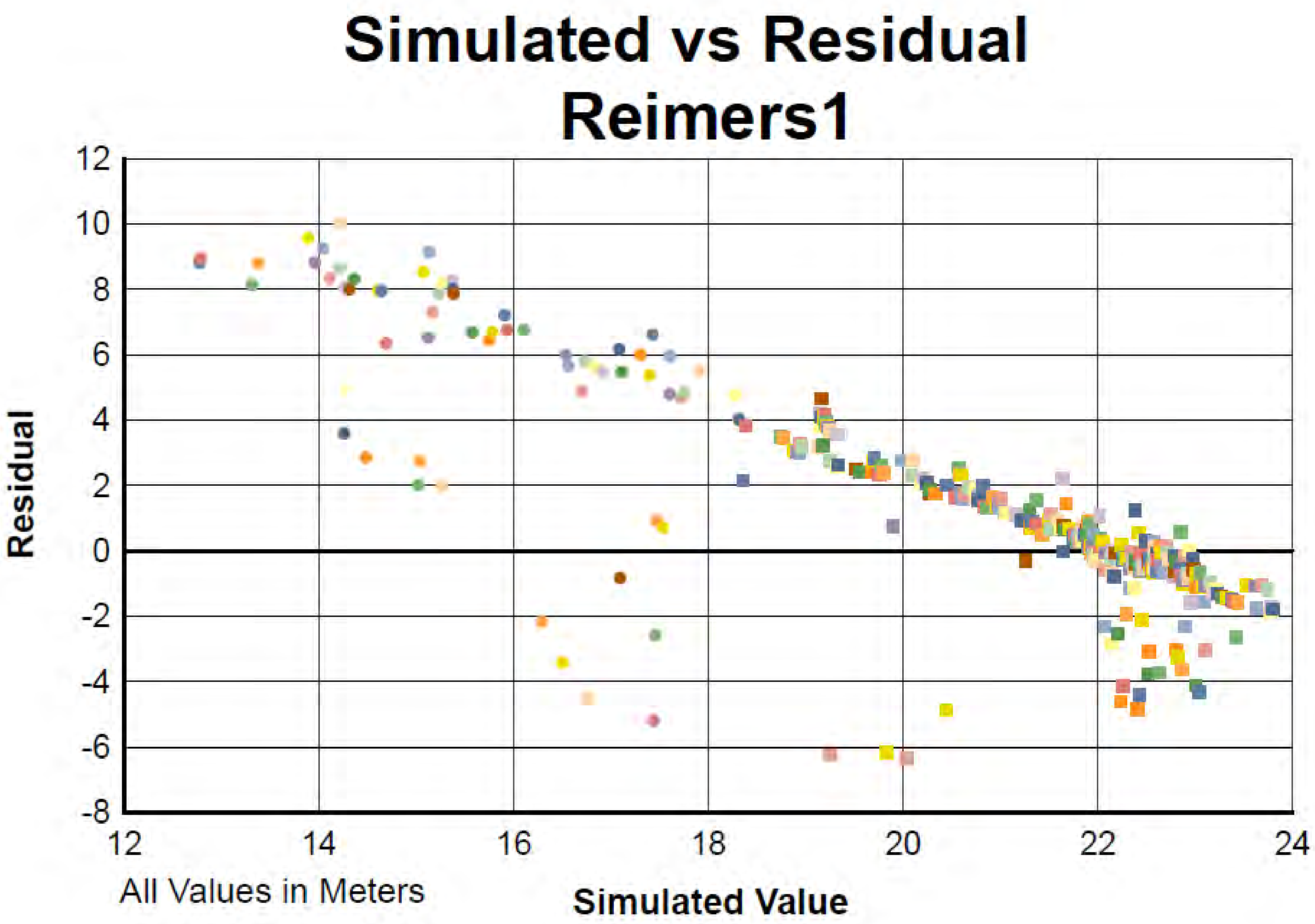

Brookdale RMSE = 2.982072
Simulated
Observed
Meters
15
10
5
1990
1995
2000
2005
2010
2015

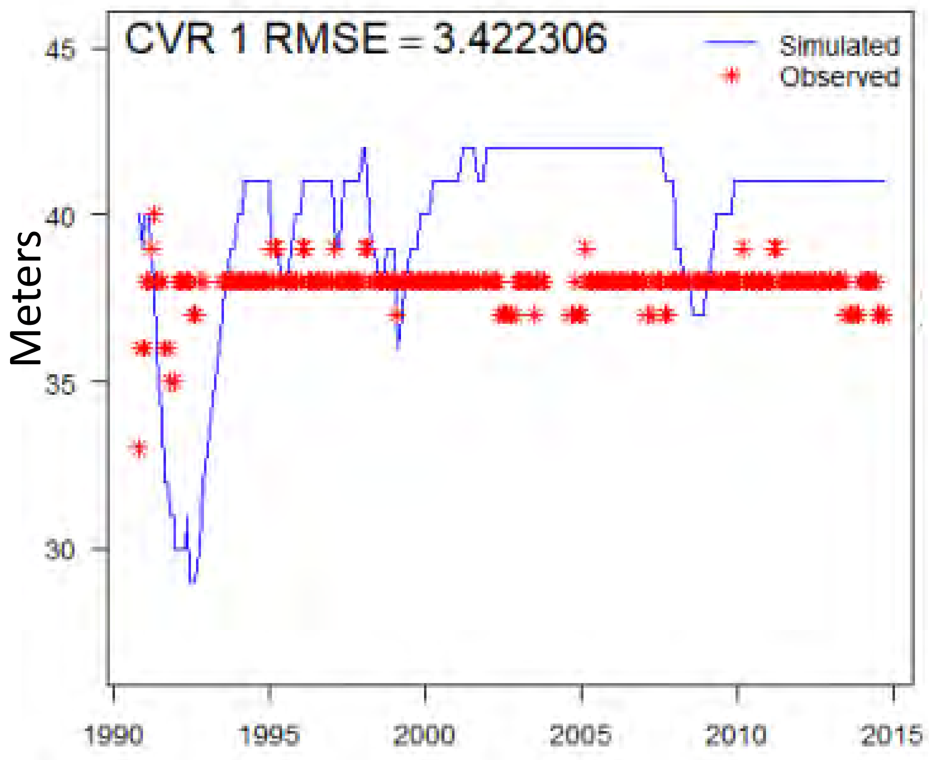

Simulated vs Residual
Brookdale
Residual
6
4
2
0
-2
-4
-6
-8
-10
2
4
6
8
10
12
14
16
18
All Values in Meters
Simulated Value


Coast Ranch RMSE = 3.041381
Simulated
Observed
Meters
4
2
0
-2
1991
1992
1993

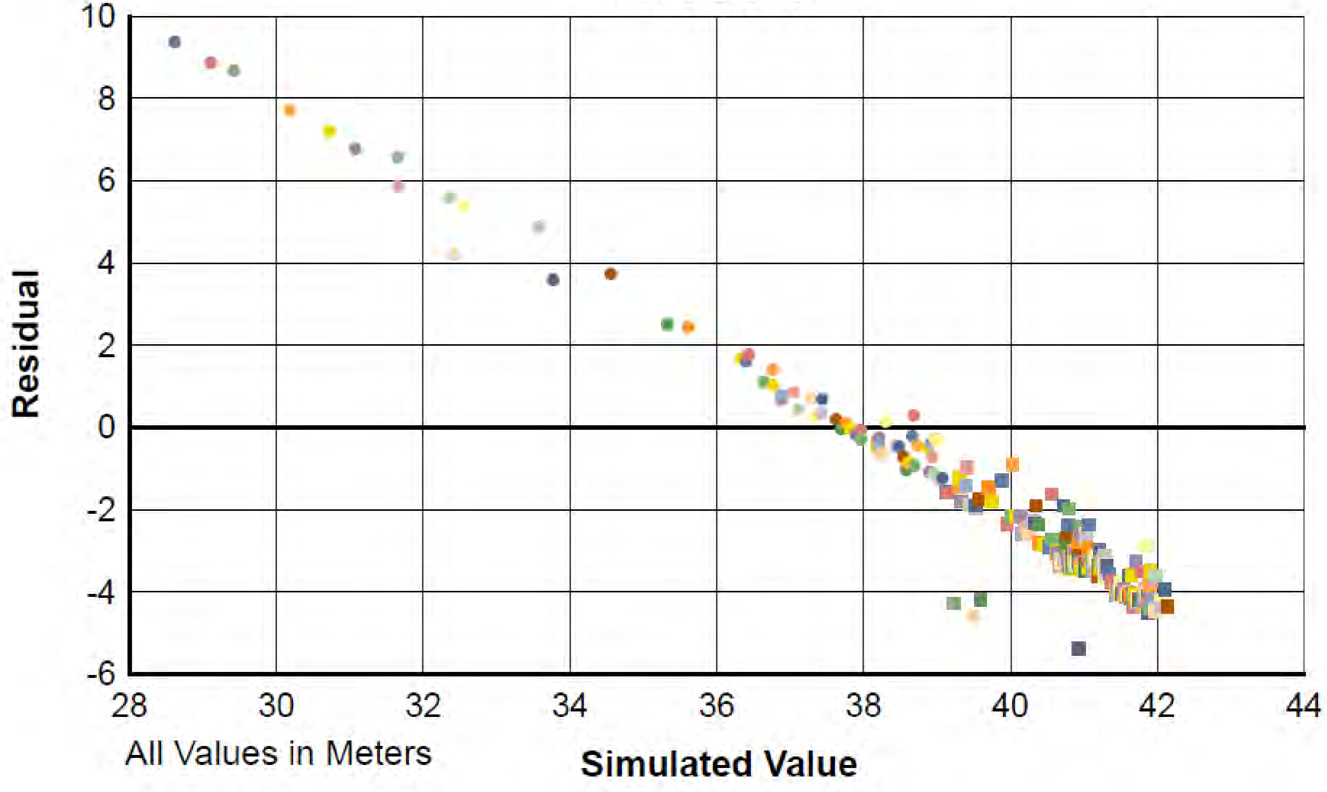

Simulated vs Residual
Coast Ranch
Residual
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
4.2
4.4
4.6
4.8
5
5.2
5.4
Simulated Value
All Values in Meters

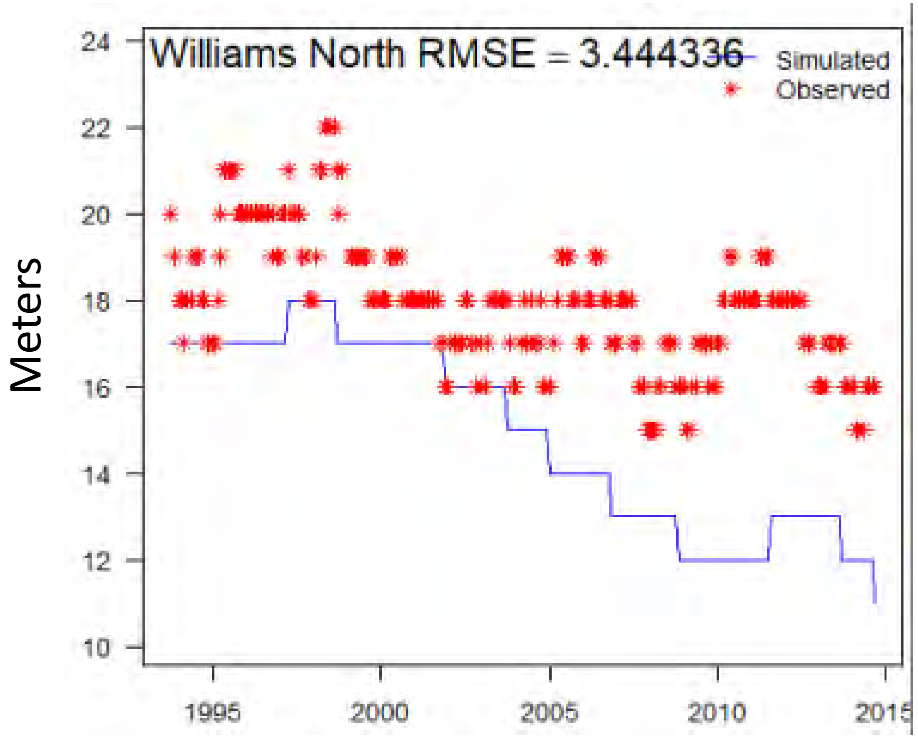

Reimers1 RMSE = 3.202611
Simulated
Observed
Meters
25
20
15
10
1990
1995
2000
2005
2010
2015

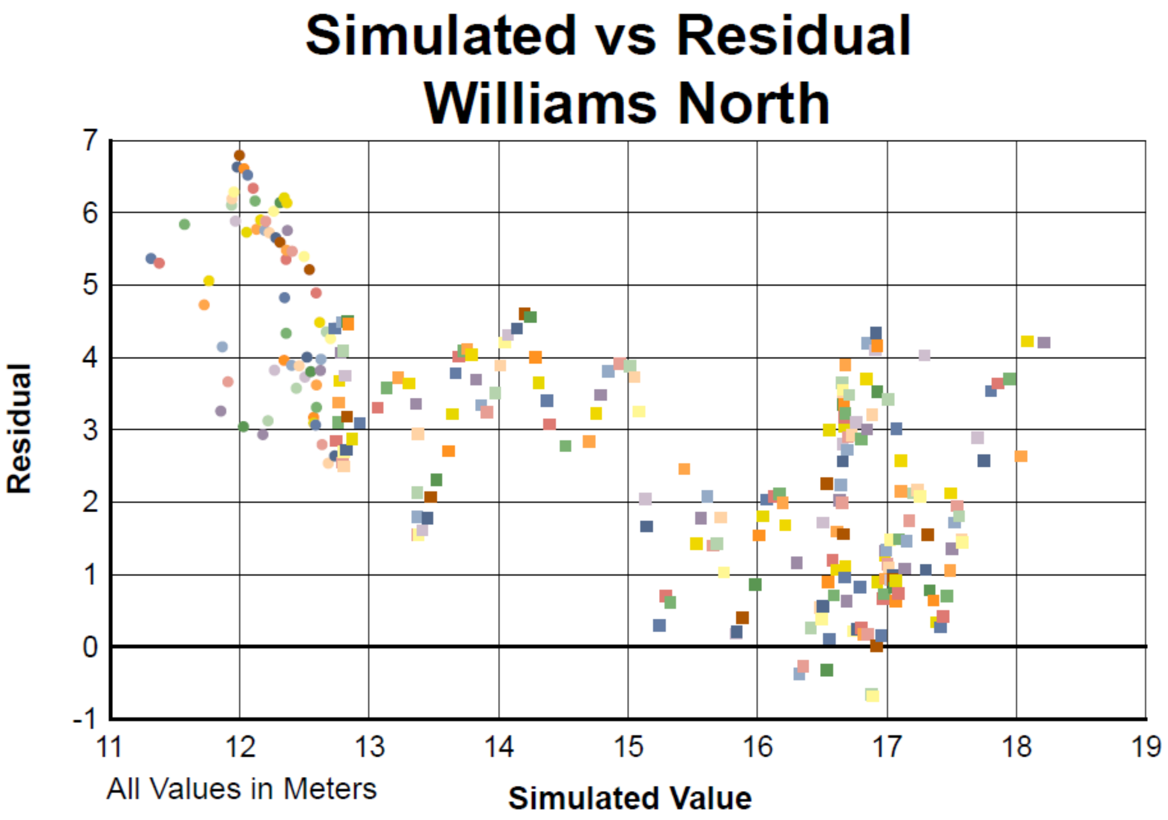

Simulated vs Residual
Reimers1
Residual
12
10
8
6
4
2
0
-2
-4
-6
-8
12
14
16
18
20
22
24
All Values in Meters
Simulated Value

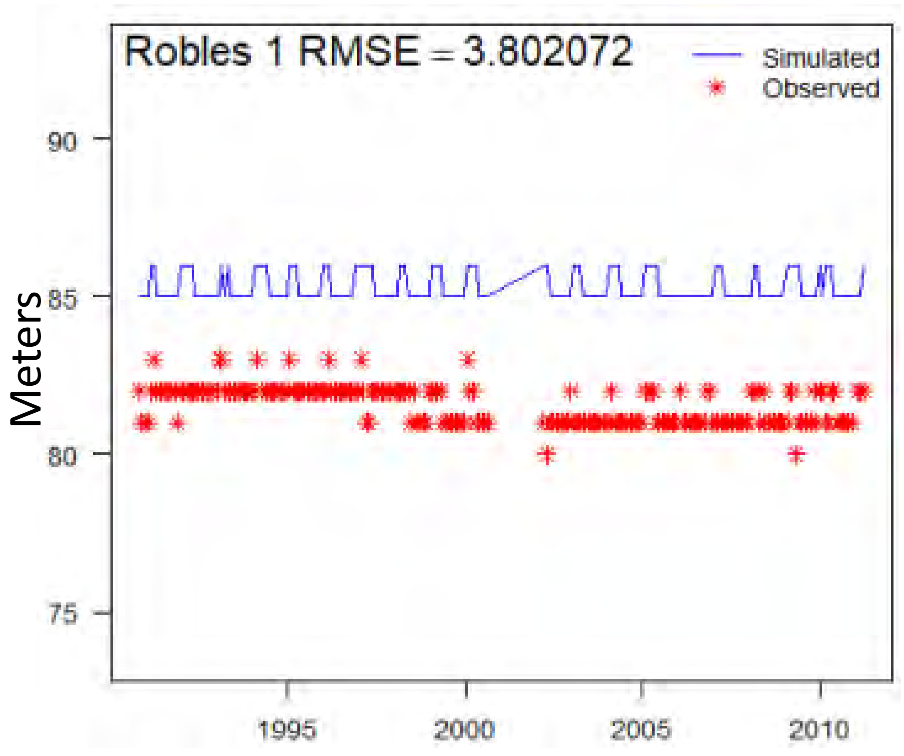


Simulated vs Residual
CVR 1

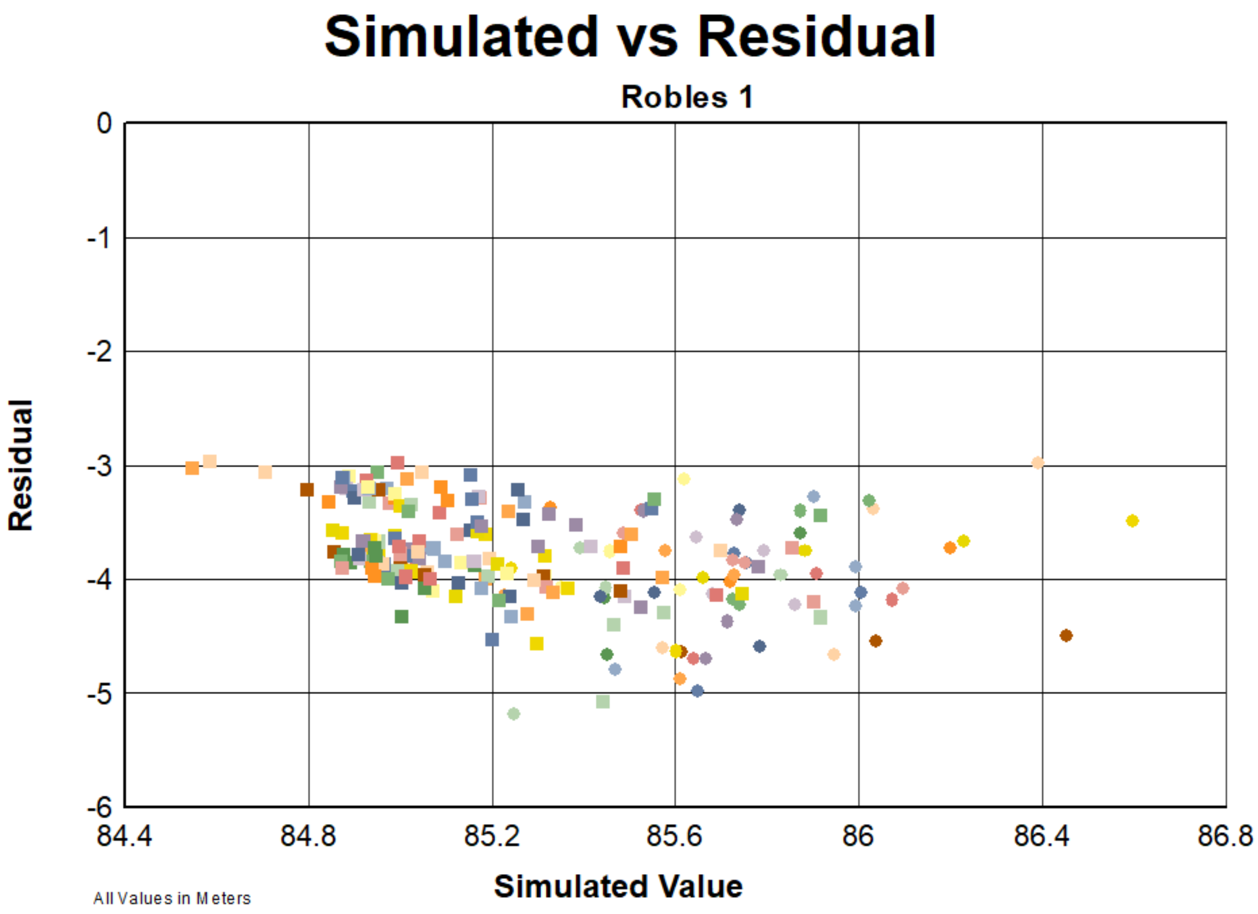



Williams North RMSE = 3.444336
Simulated
Observed
Meters
24
22
20
18
16
14
12
10
1995
2000
2005
2010
2015

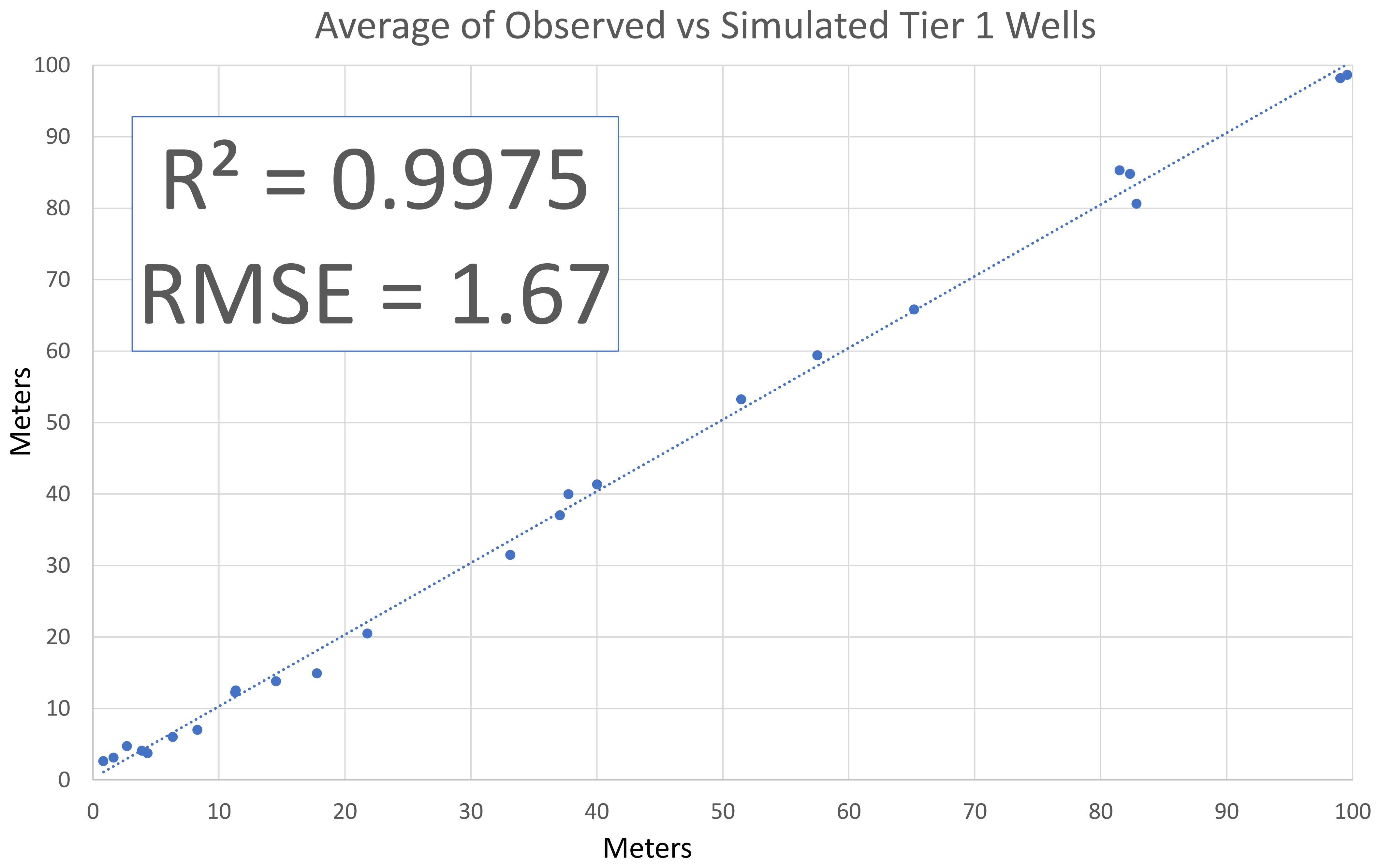

Simulated vs Residual
Williams North
Residual
7
6
5
4
3
2
1
0
-1
11
12
13
14
15
16
17
18
19
All Values in Meters
Simulated Value



Robles 1 RMSE = 3.802072
Simulated
Observed
Meters
90
85
80
75
1995
2000
2005
2010

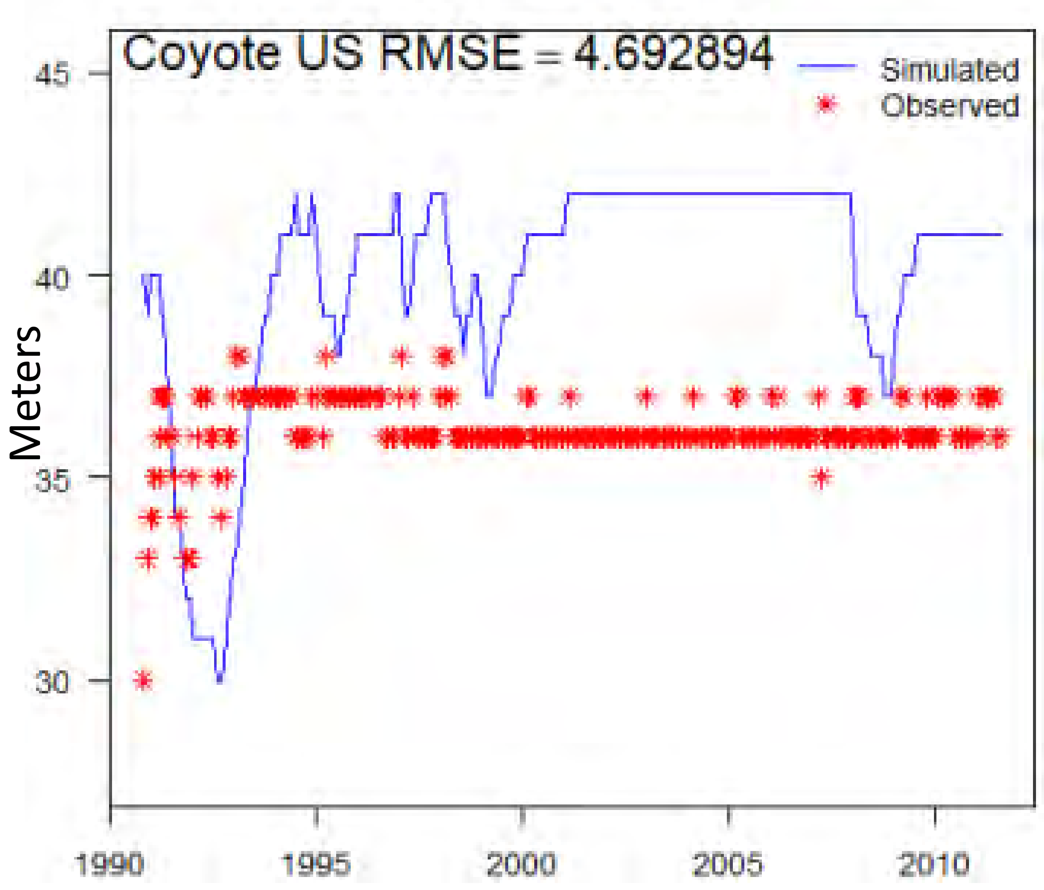


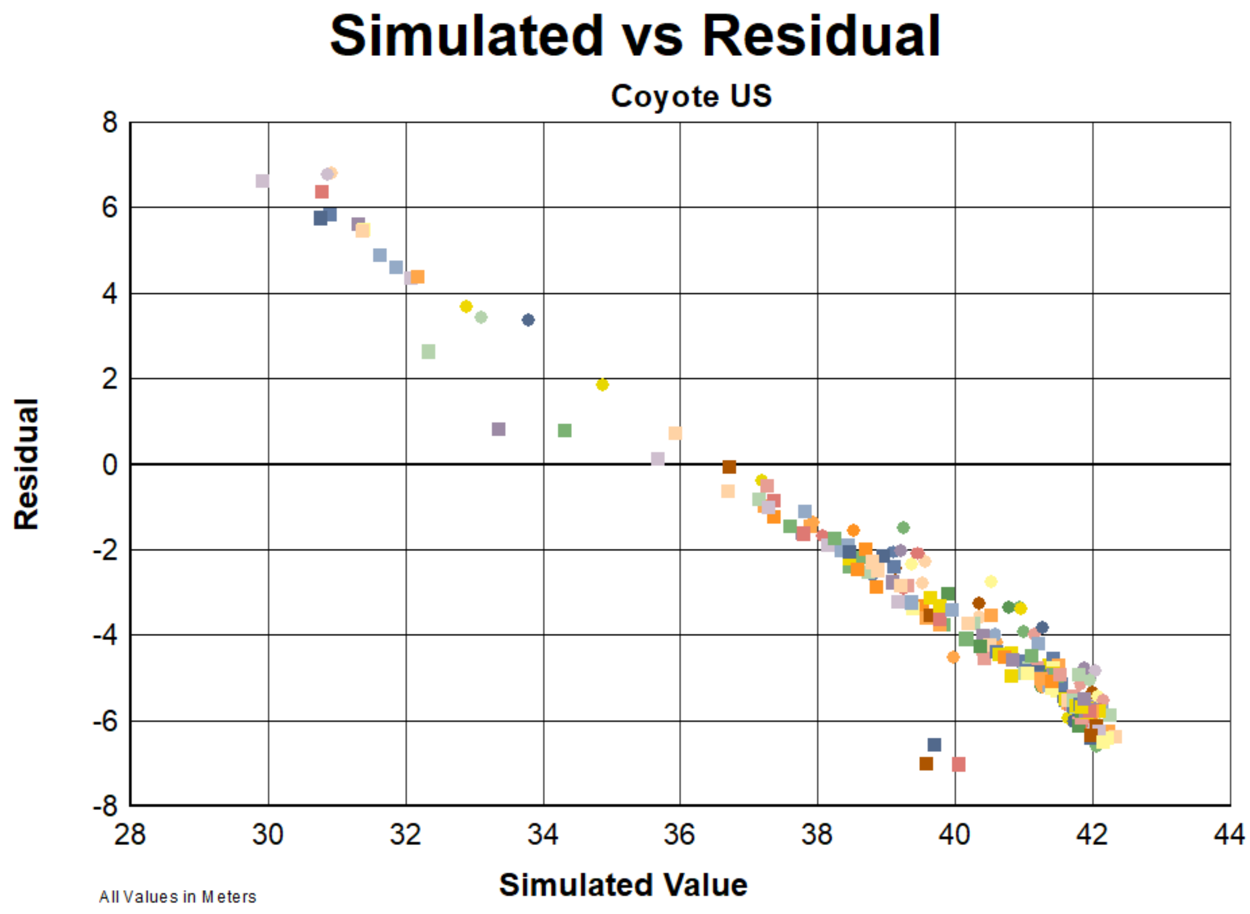
Simulated vs Residual
Robles 1
Residual
0
-1
-2
-3
-4
-5
-6
84.4
84.8
85.2
85.6
86
86.4
86.8
Simulated Value
All Values in Meters

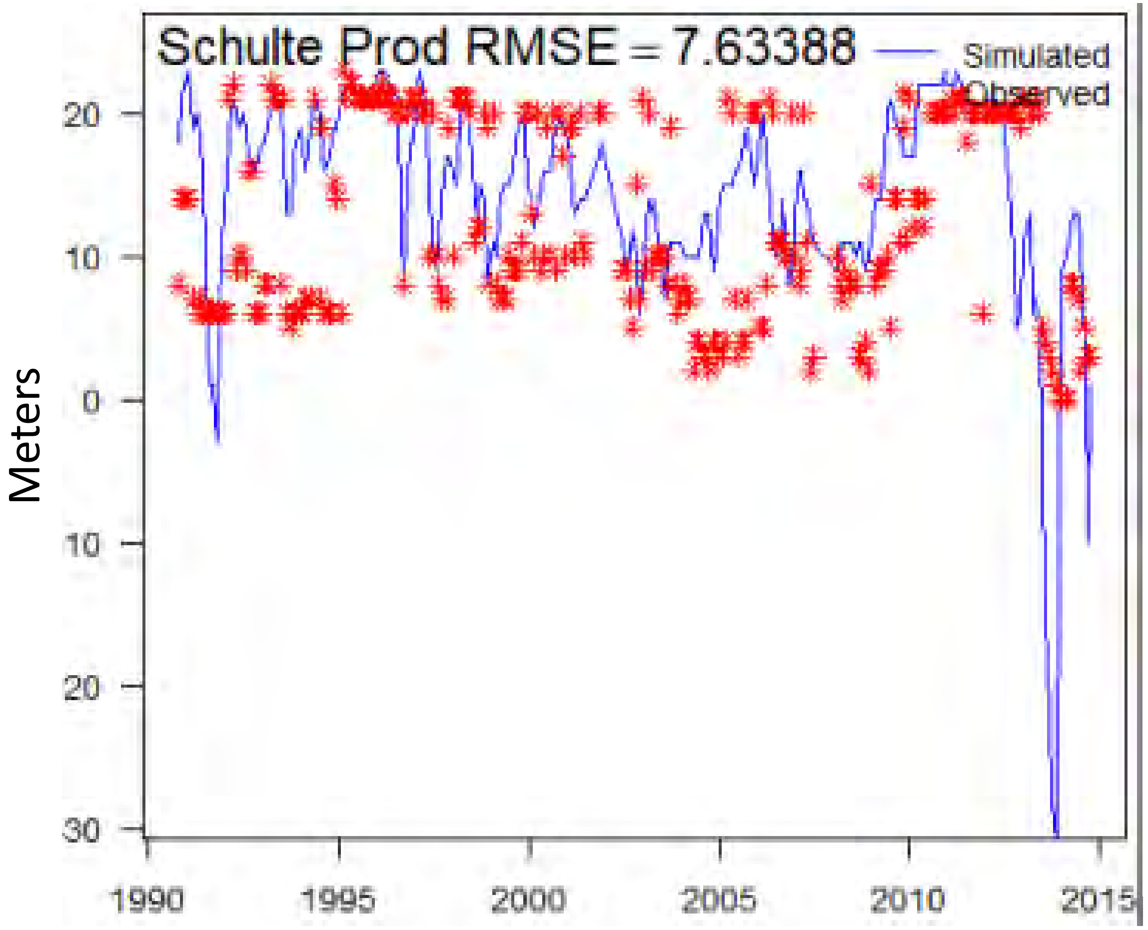


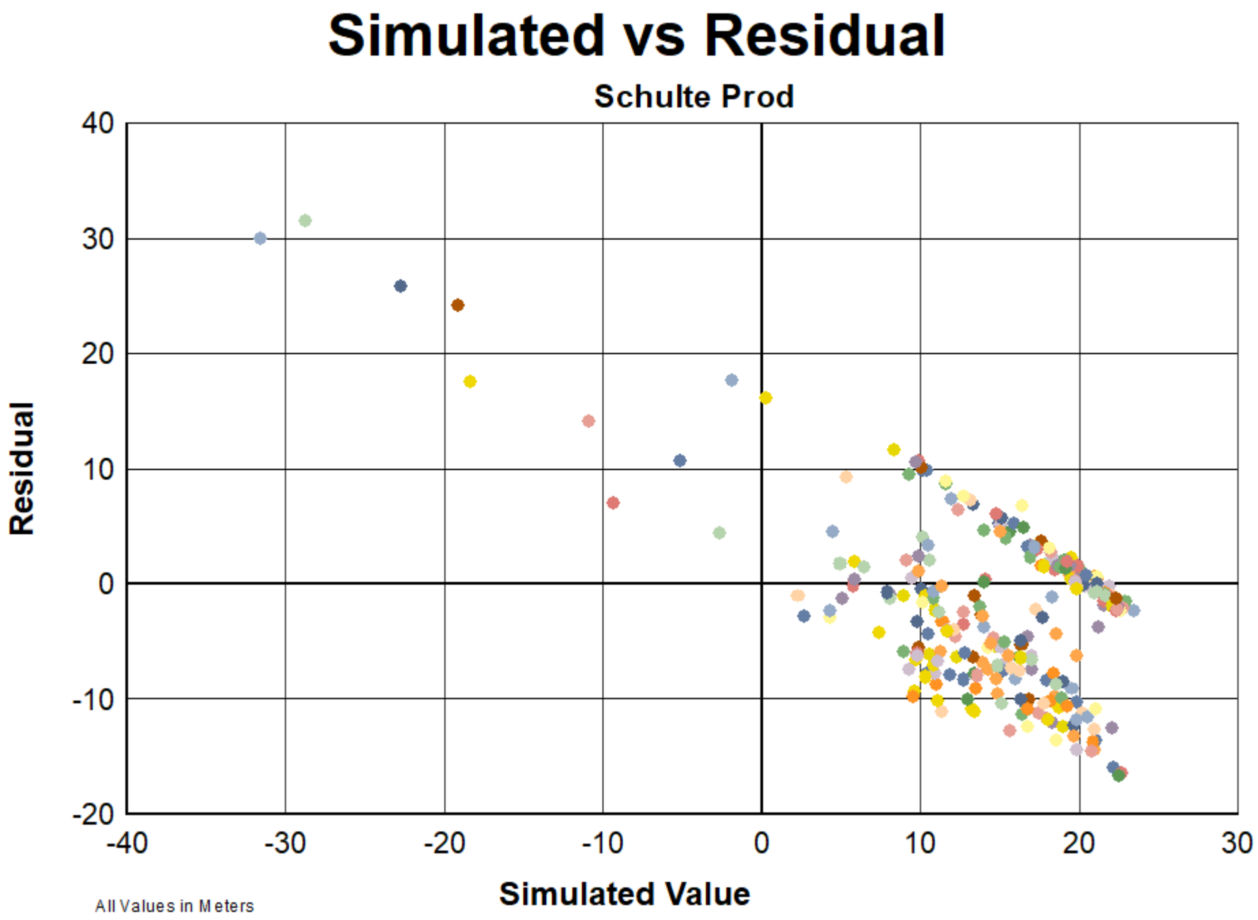
Average of Observed vs Simulated Tier 1 Wells
R2 = 0.9975
RMSE = 1.67
Meters
Meters
0
10
20
30
40
50
60
70
80
90
100

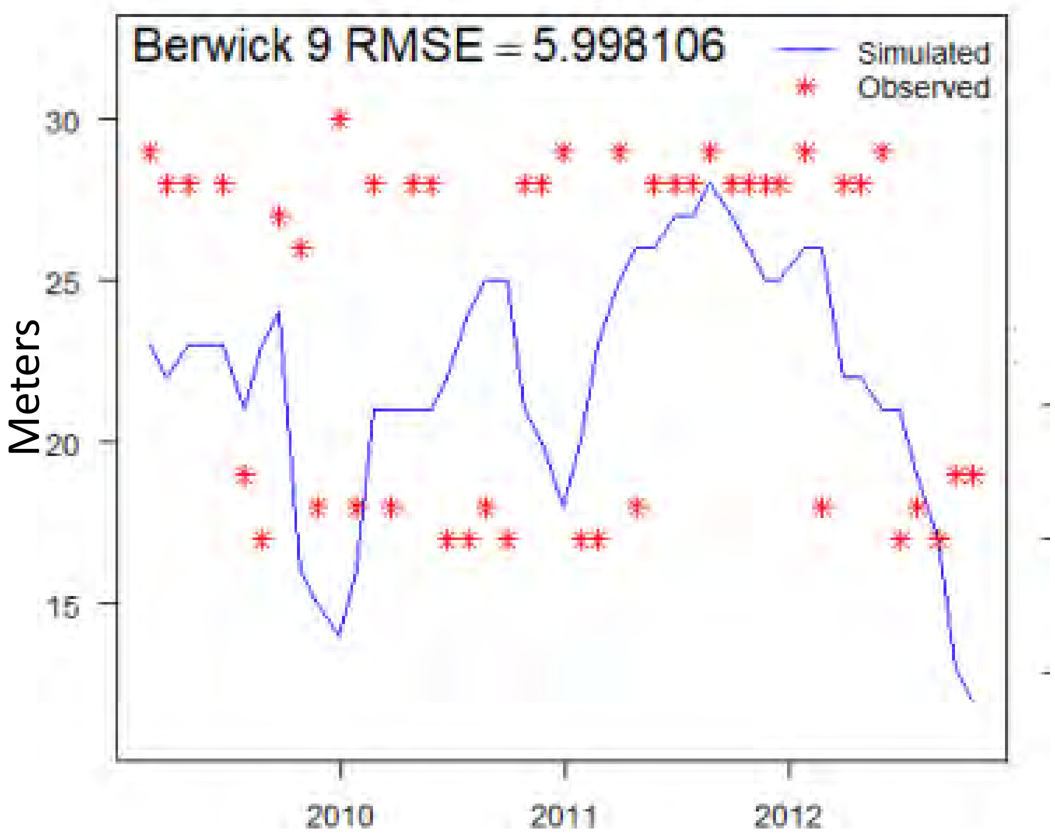
Examples of Second Tier Wells



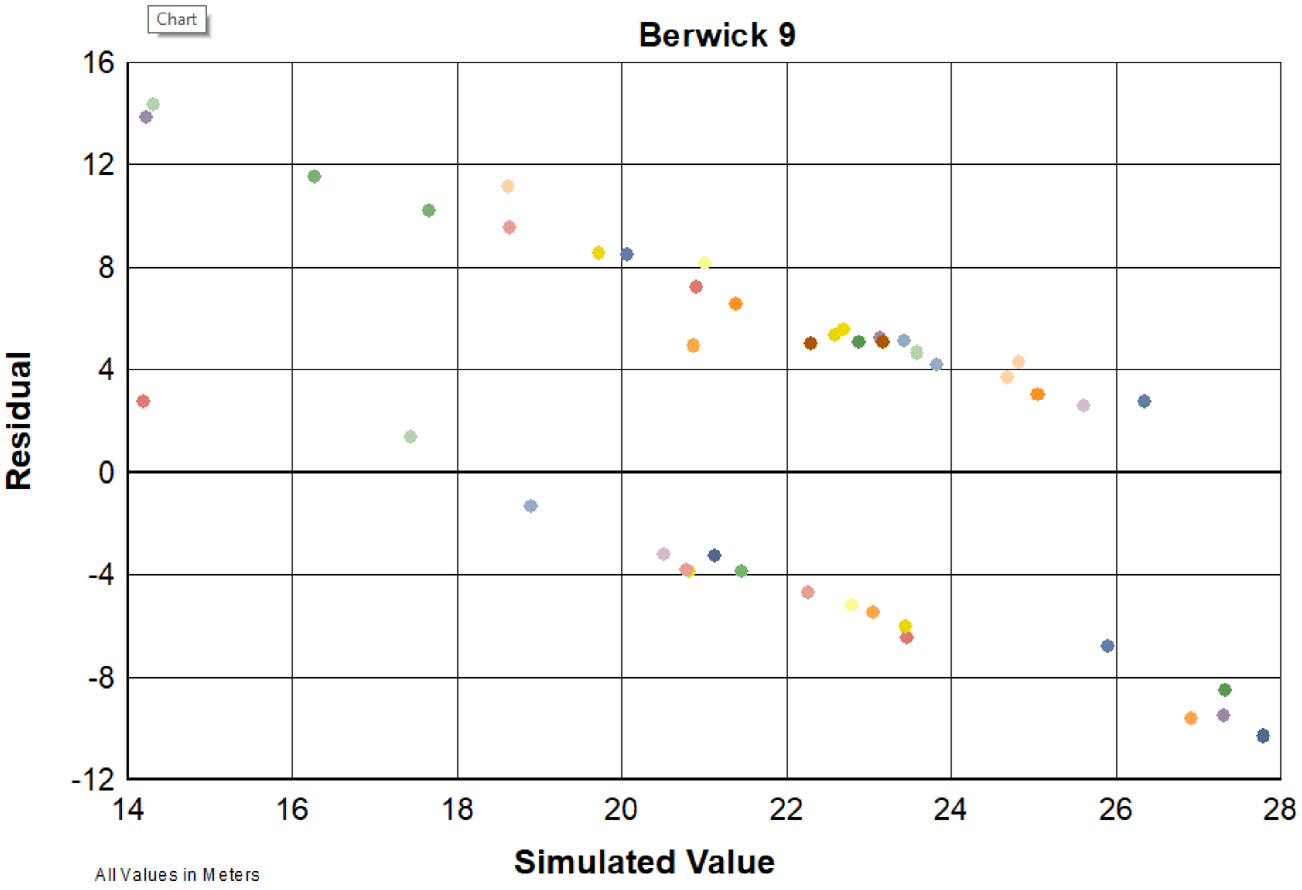



Schulte Prod RMSE = 7.63388
Simulated
Observed
Meters
20
10
0
10
20
30
1990
1995
2000
2005
2010
2015

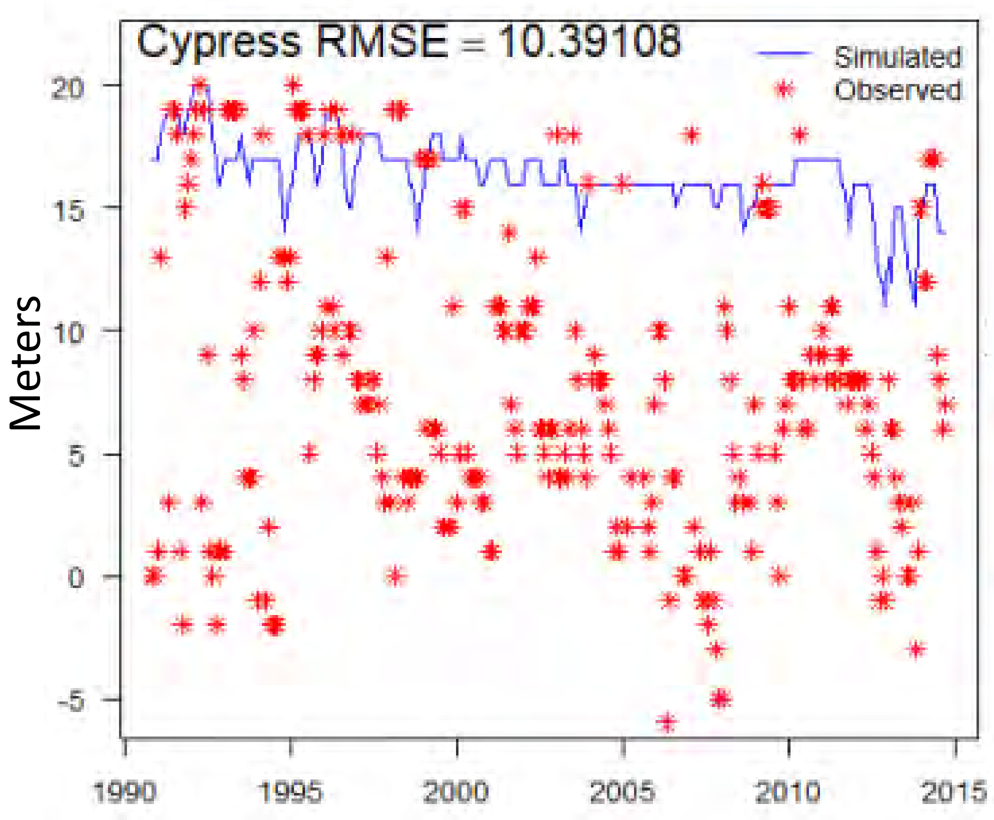

Simulated vs Residual
Schulte Prod
Residual
40
30
20
10
0
-10
-20
-40
-30
-20
-10
0
10
20
30
Simulated Value
All Values in Meters

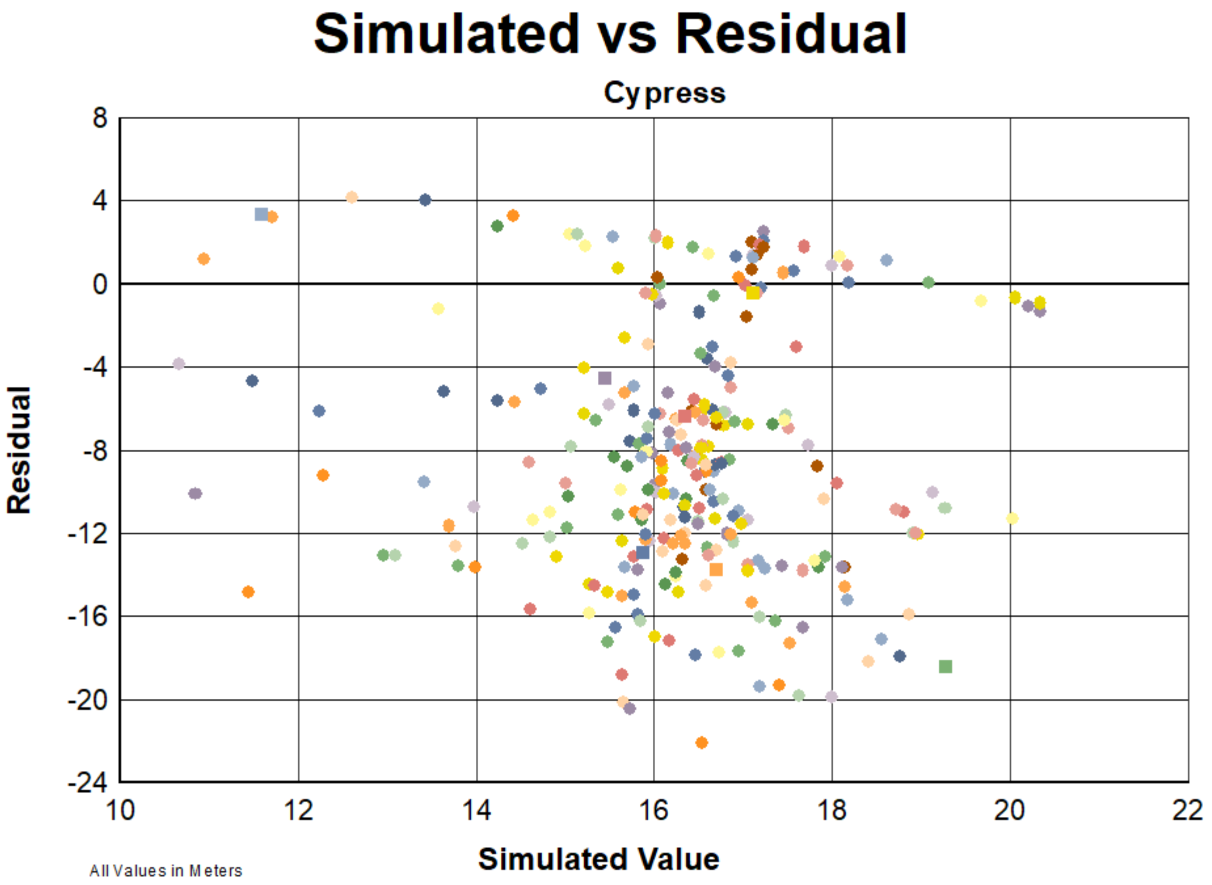


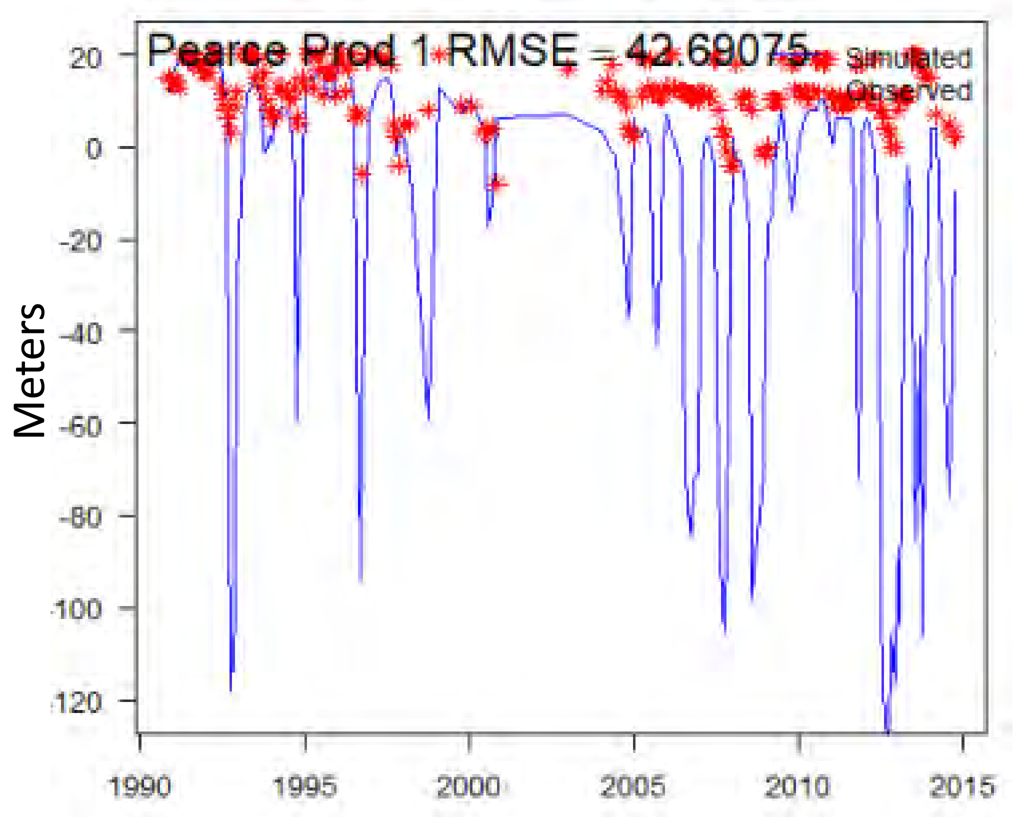
Simulated vs Residual

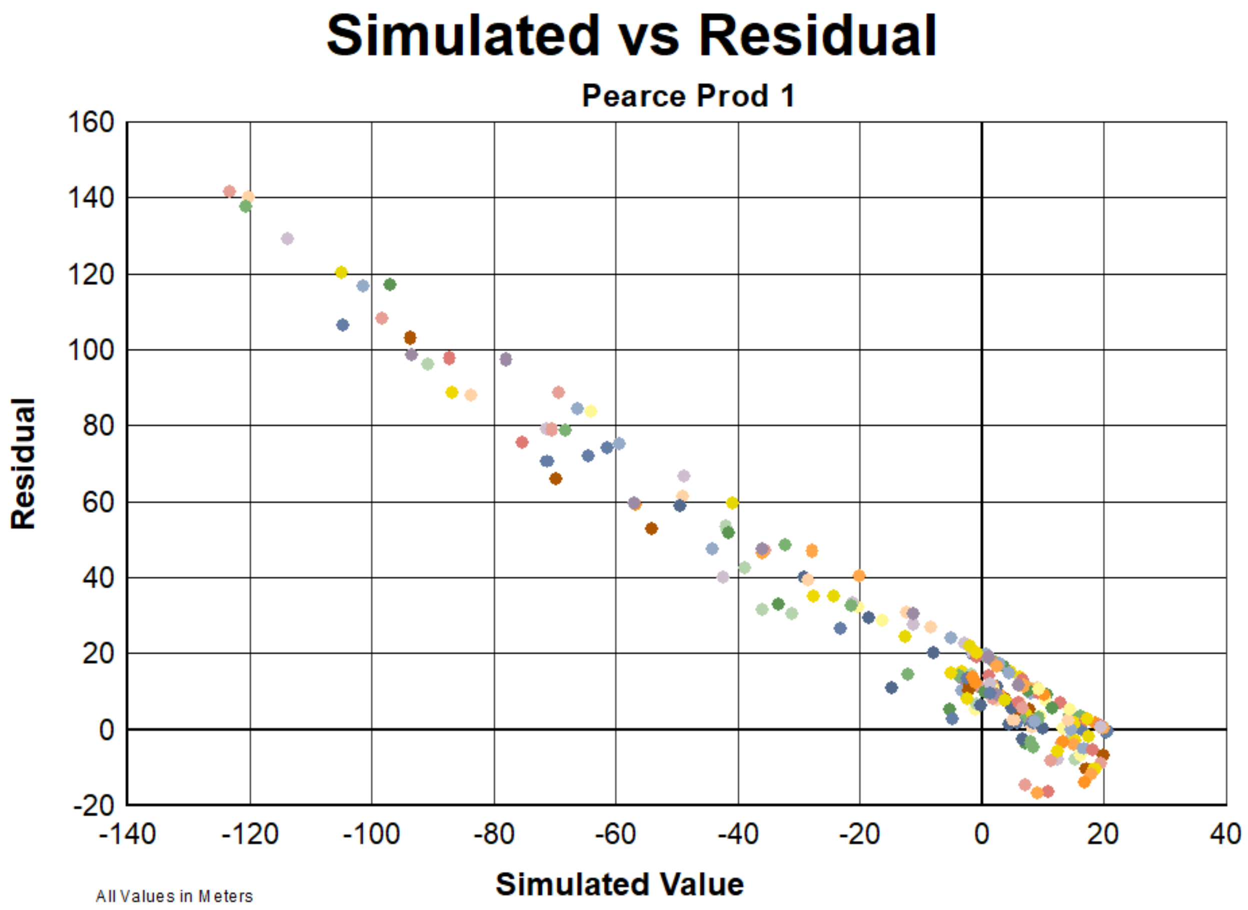


Examples of Third Tier Wells



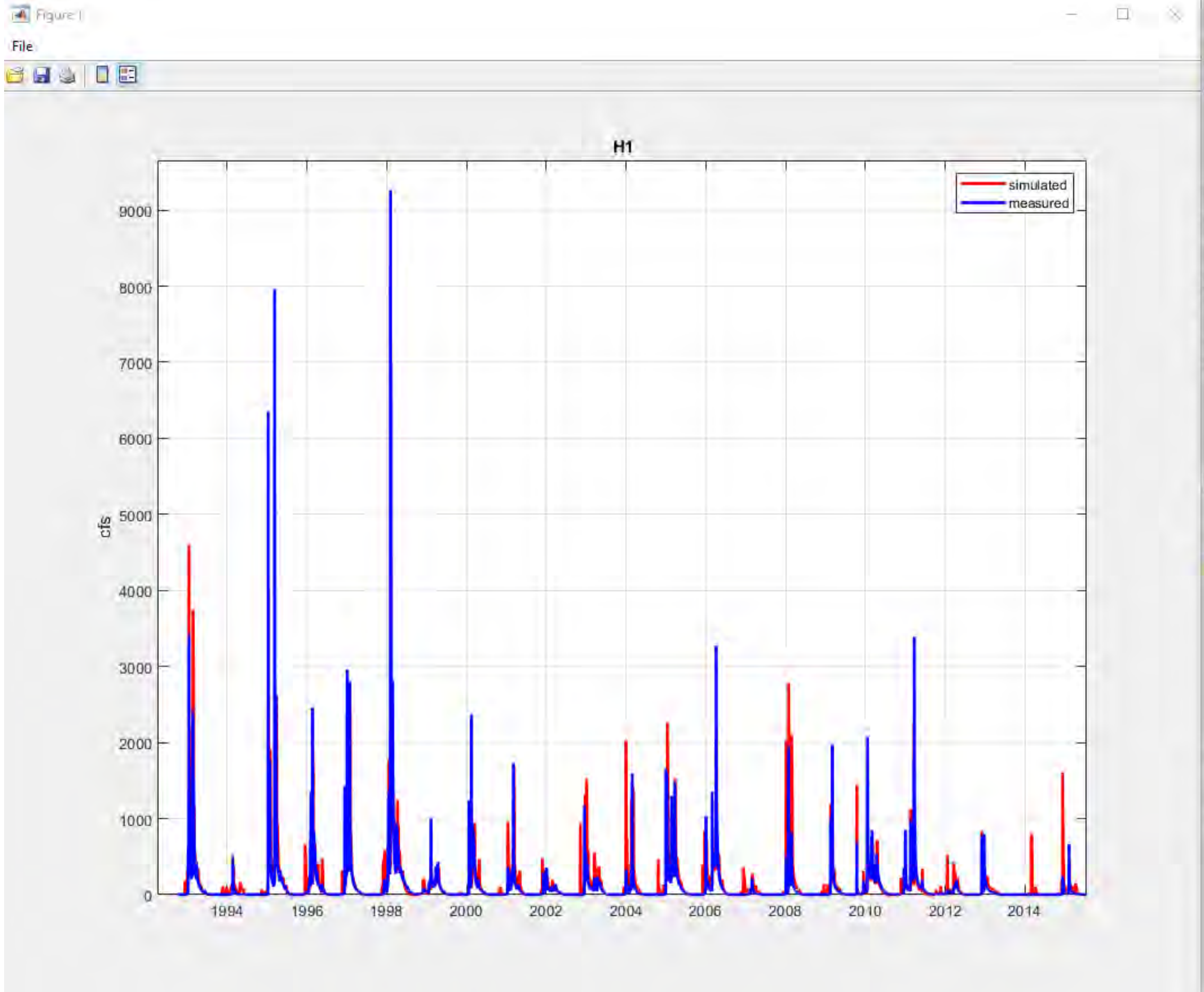


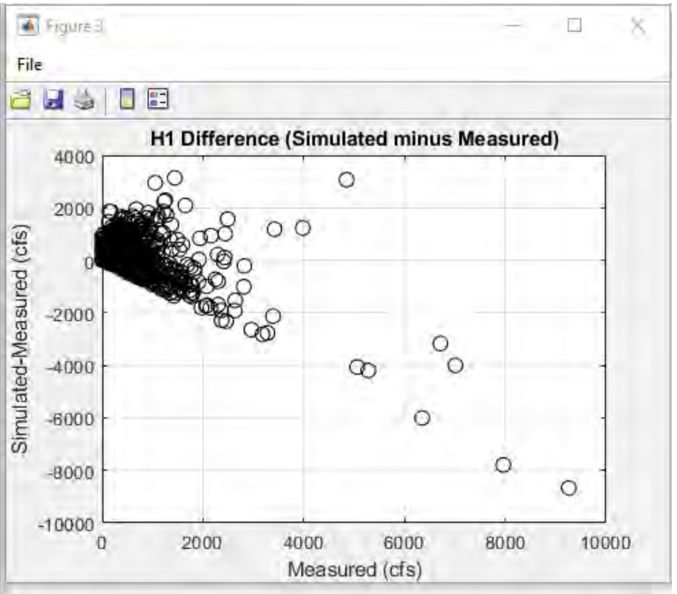

Pearce Prod 1 RMSE = 42.69075
Simulated
Observed
Meters
20
0
-20
-40
-60
-80
-100
-120
1990
1995
2000
2005
2010
2015

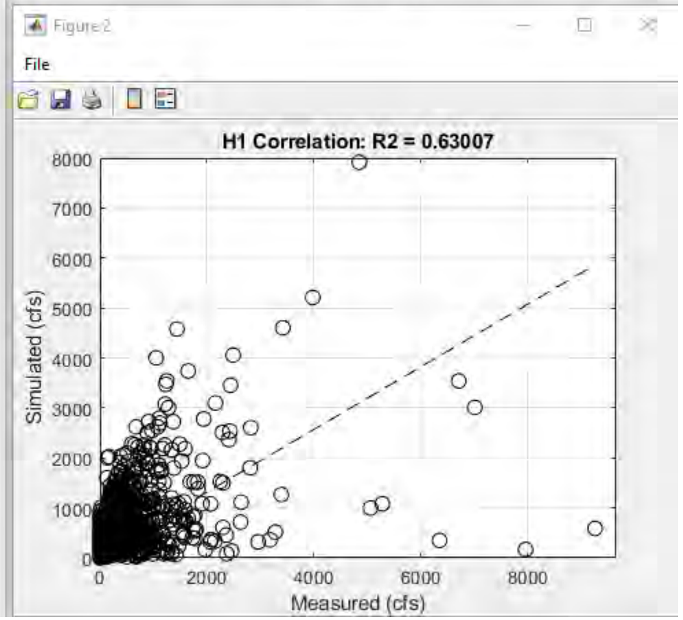

Simulated vs Residual
Pearce Prod 1
Residual
Simulated Value
All Values in Meters
160
140
120
100
80
60
40
20
0
-20
-140
-120
-100
-80
-60
-40
-20
0
20
40

Some additional hydrographs from the last presentation showing results of the CRBHM

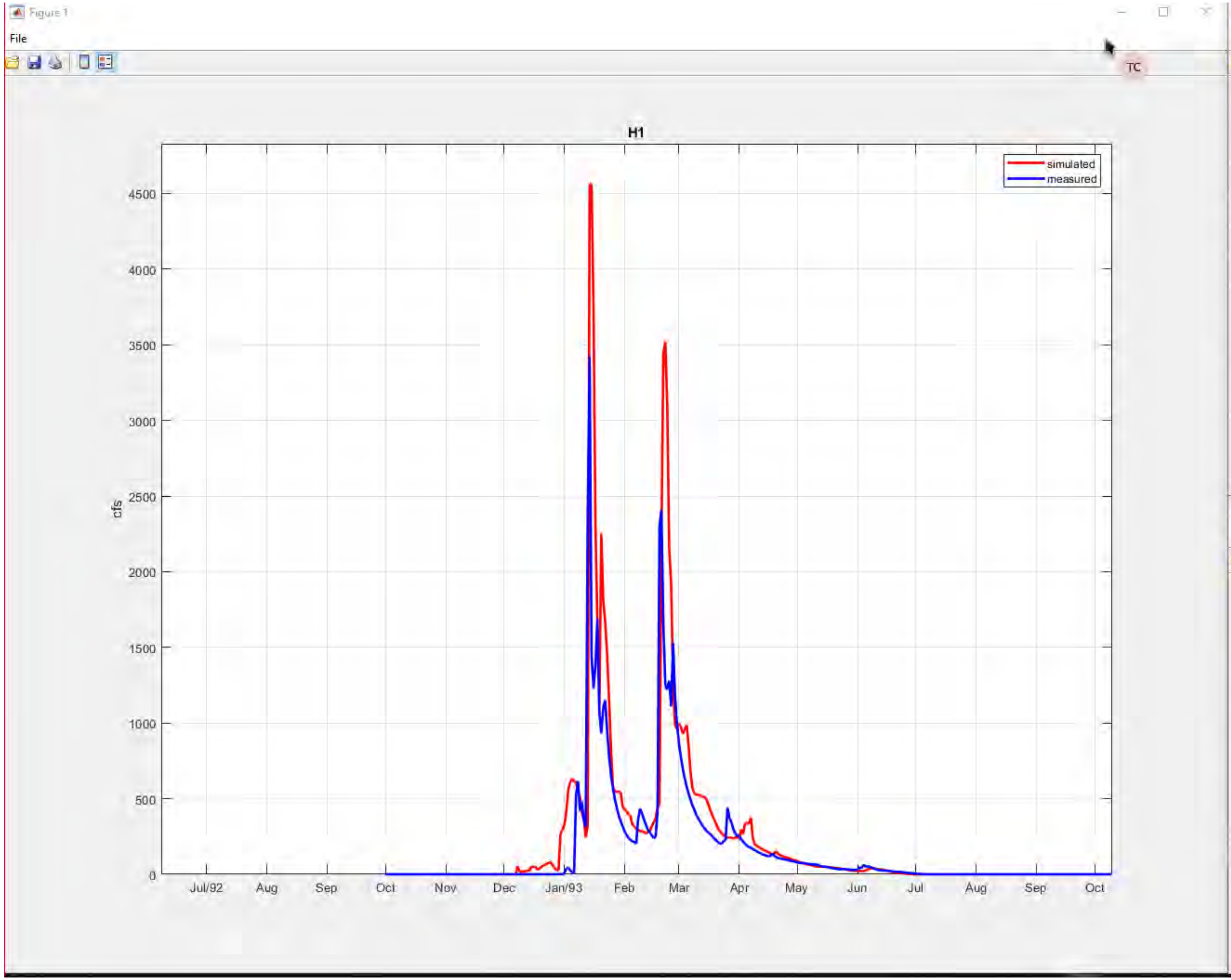
Highway One Gage – Entire Simulation

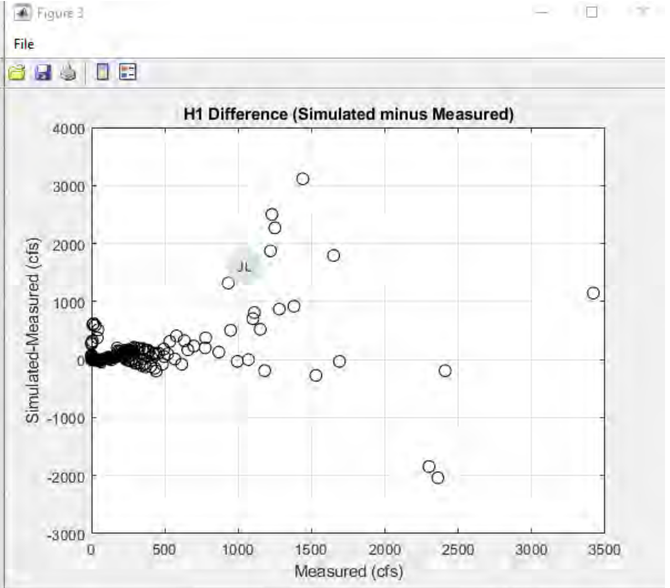


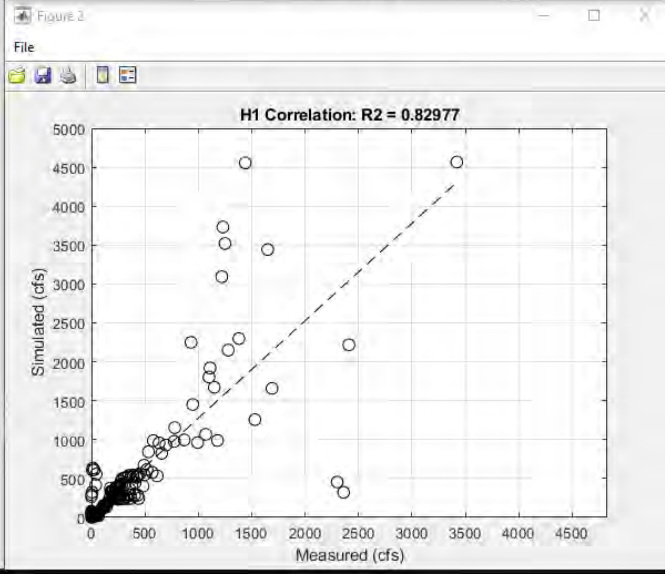




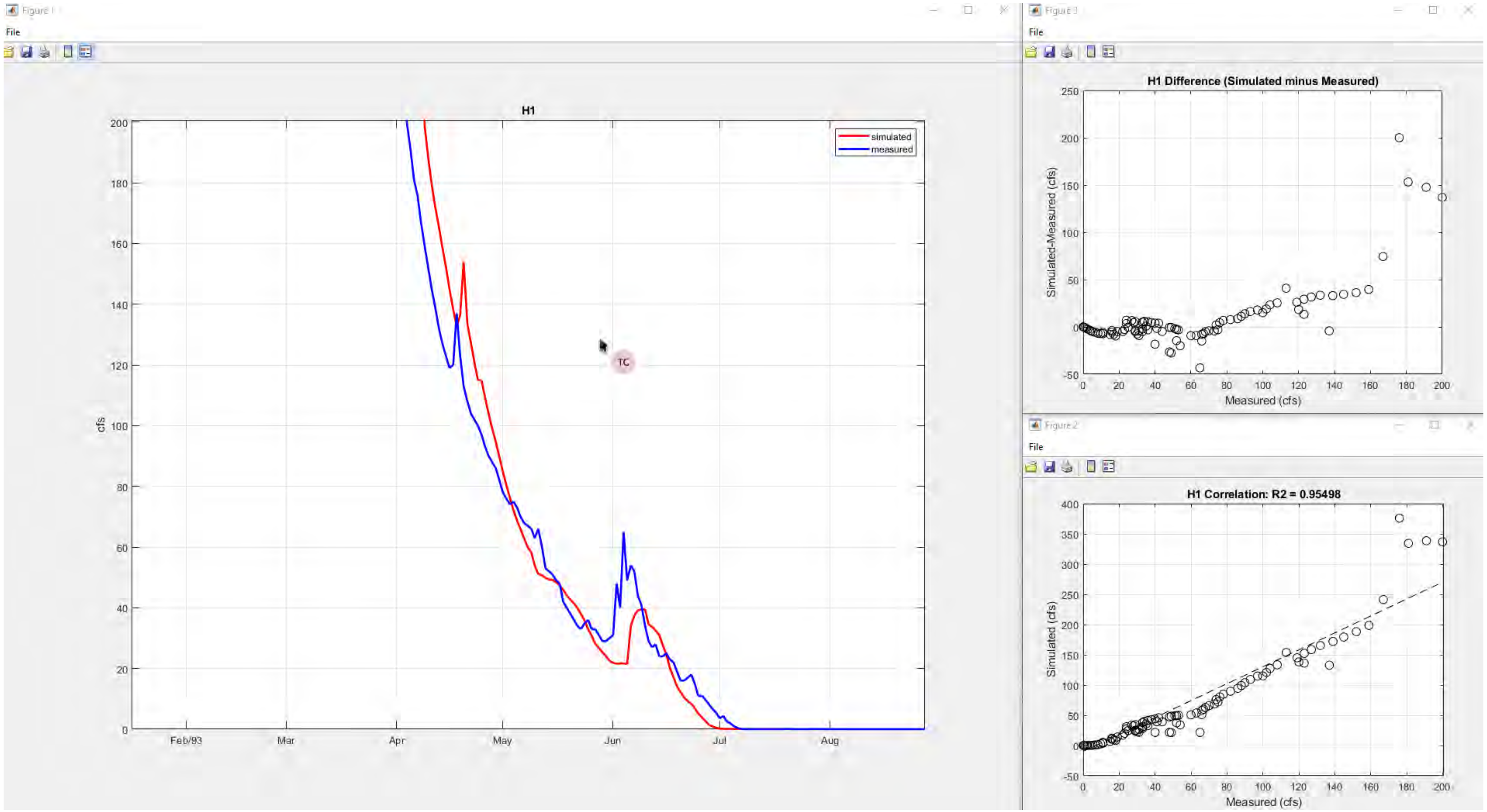
Highway One Water Year 1993



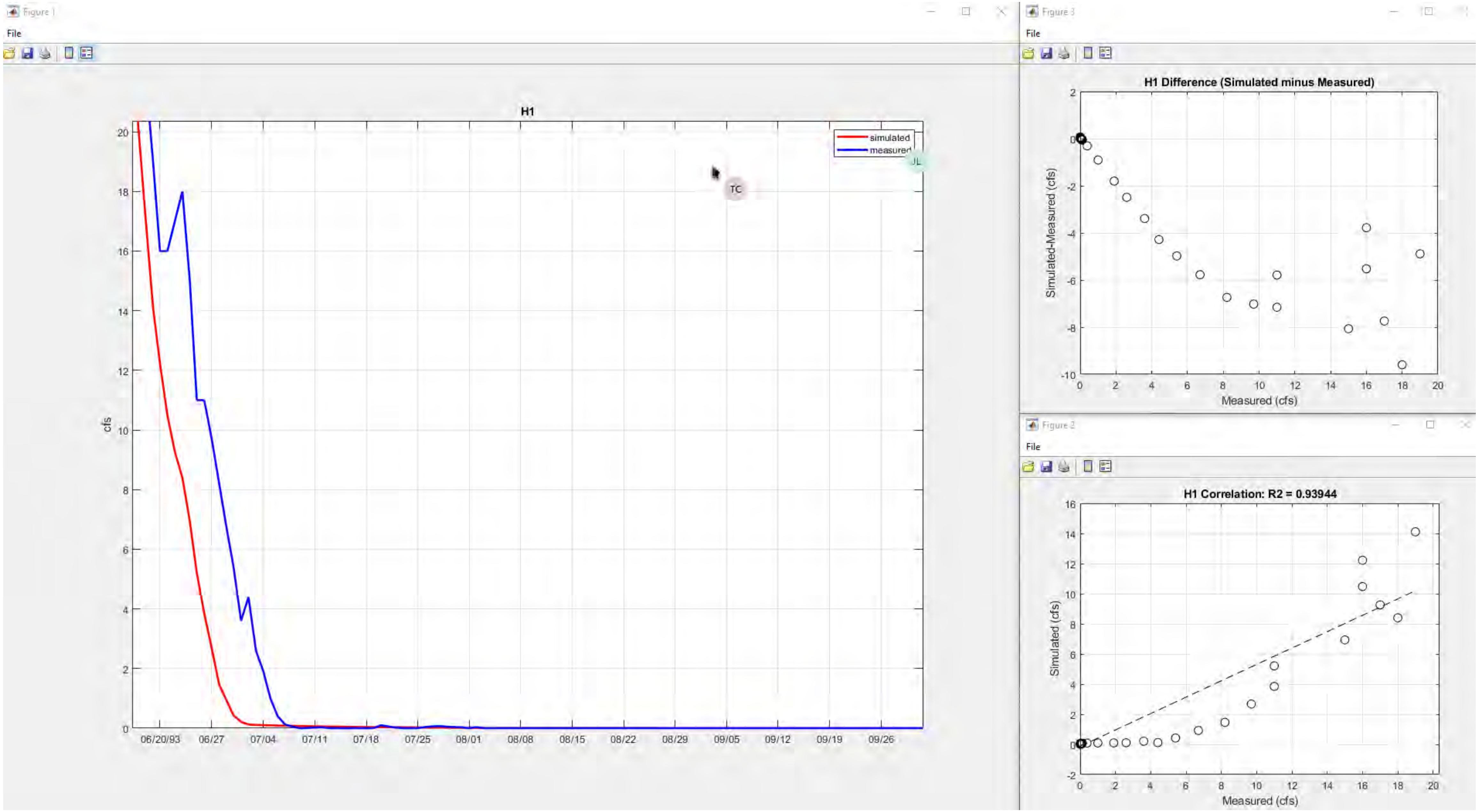




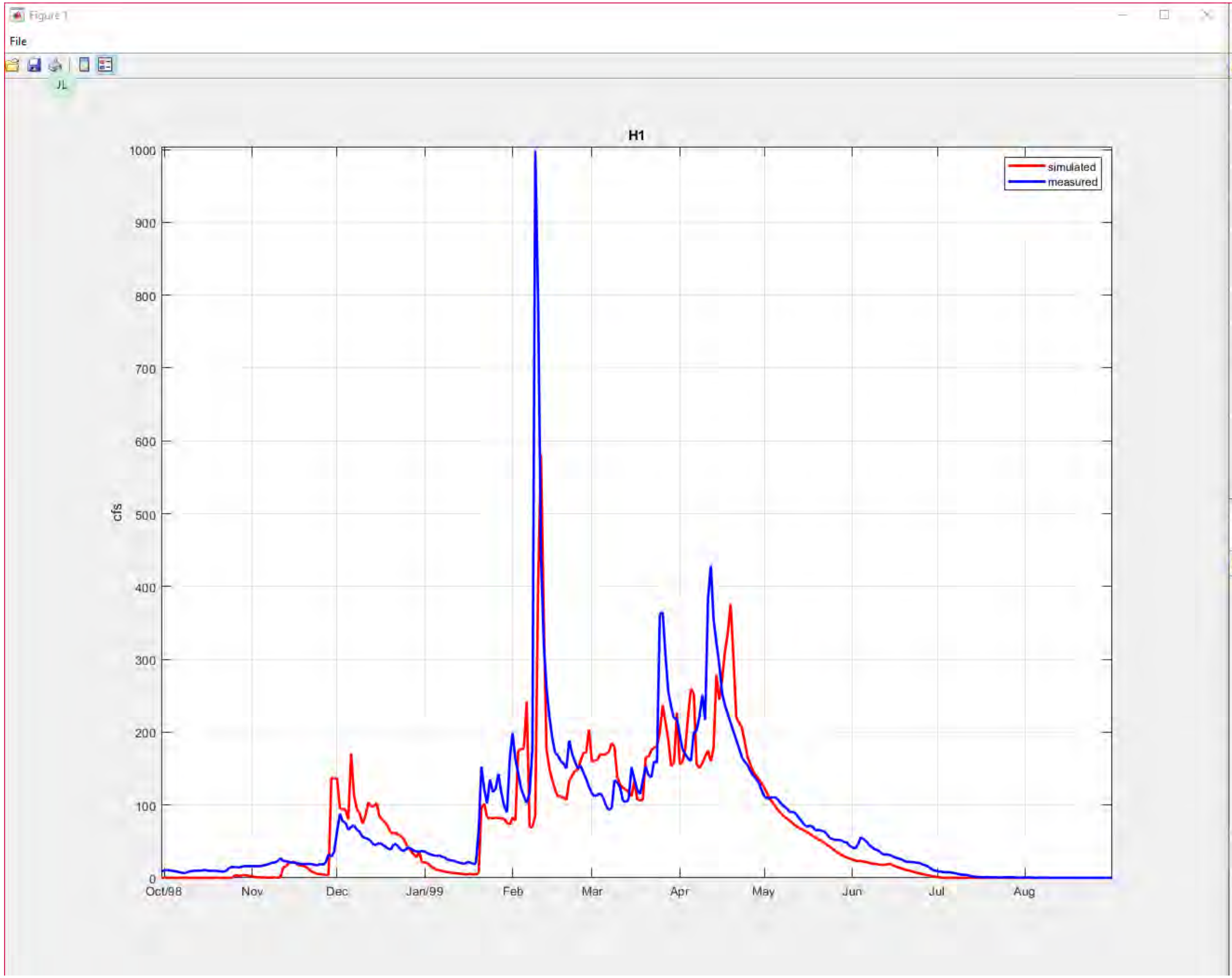
Highway One Water Year 1993 – Spring Recession under 200 cfs

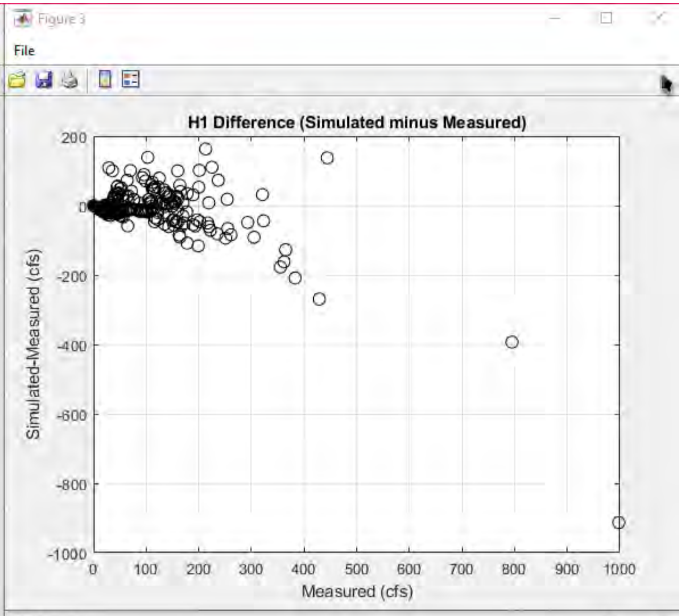


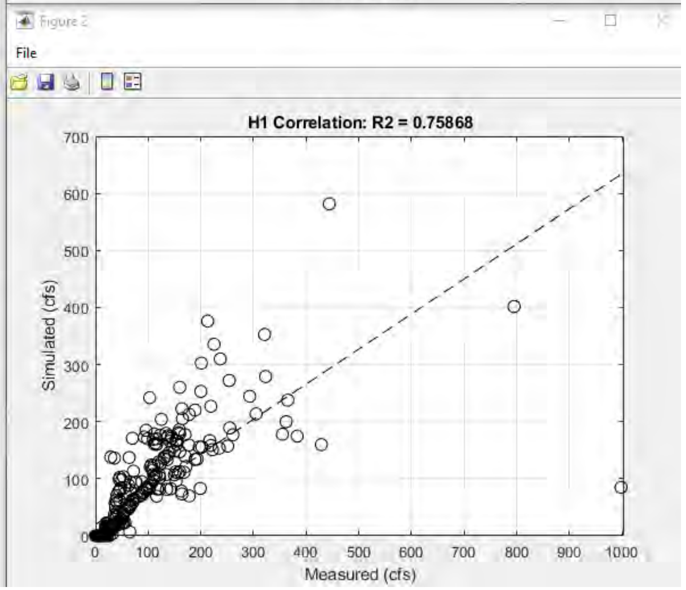
Highway One Water Year 1993 – End of Season Recession under 20 cfs



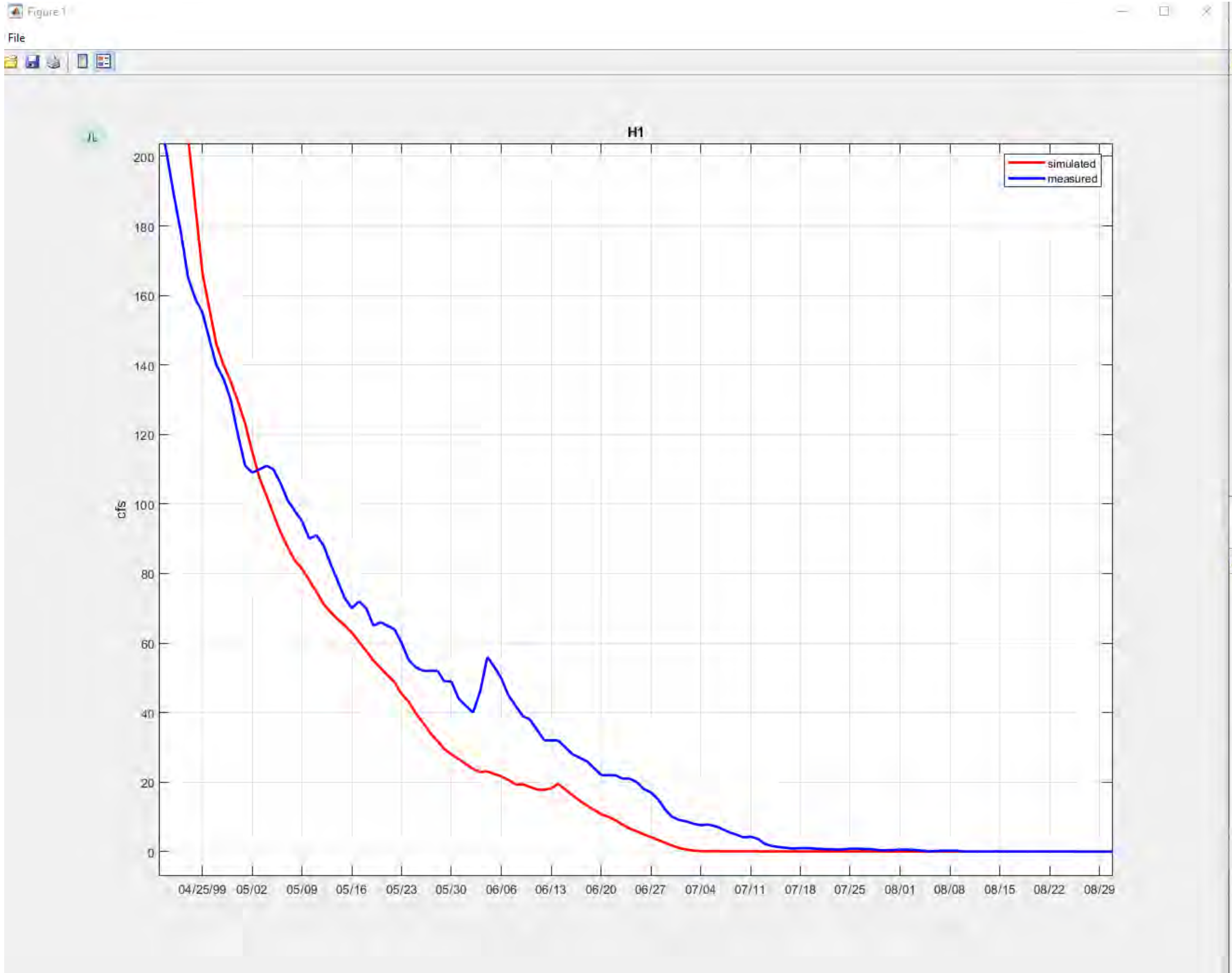
Highway One Water Year 1999

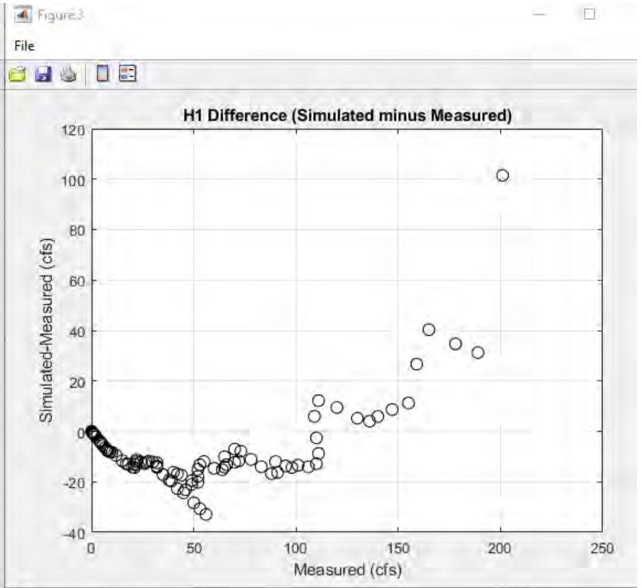


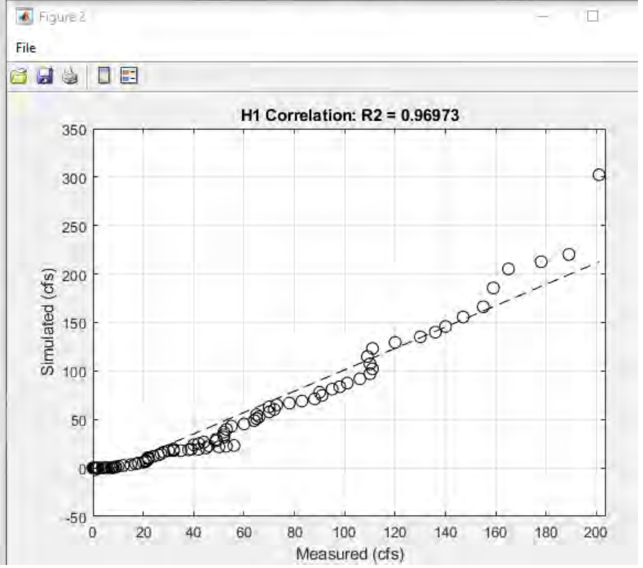




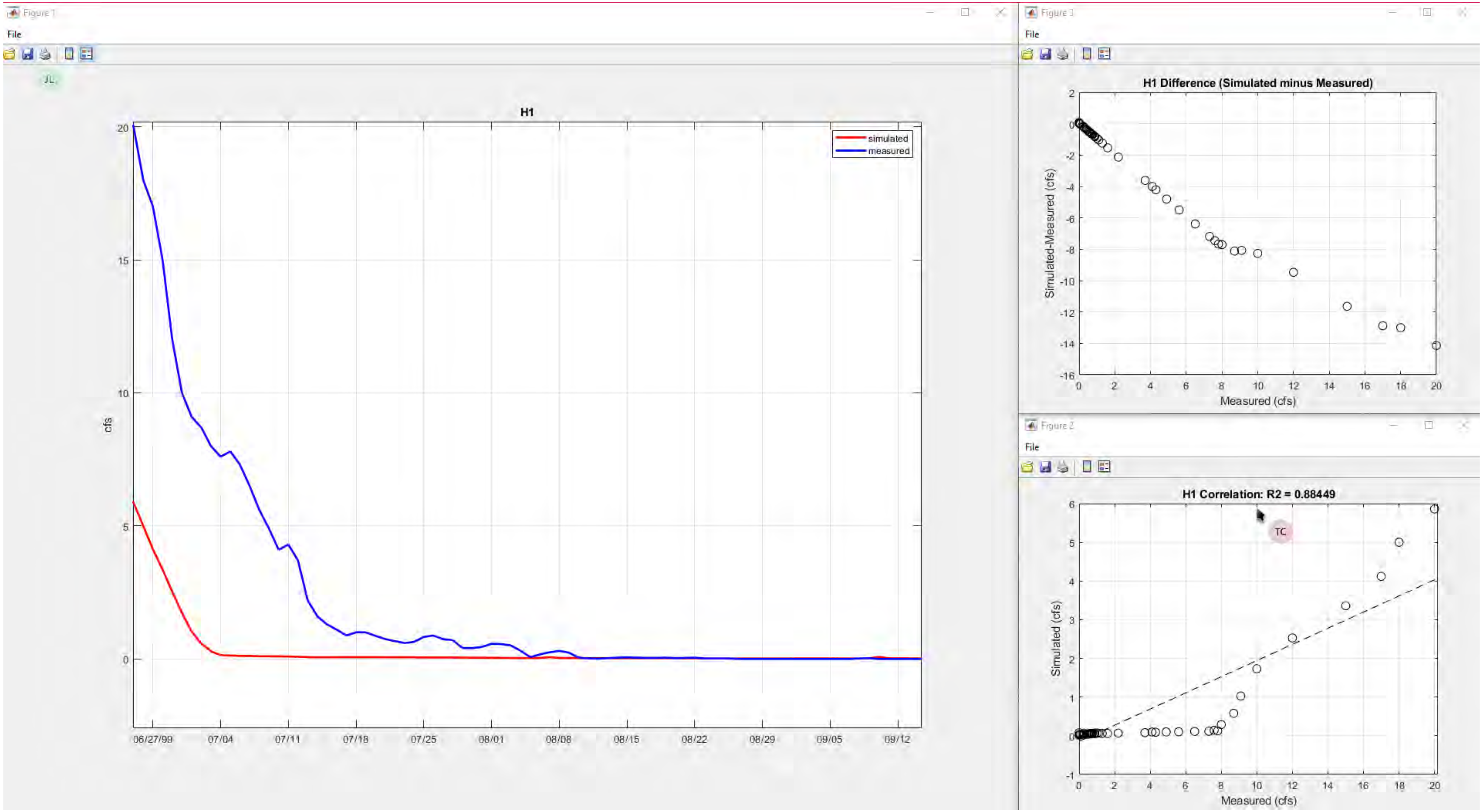
Highway One Water Year 1999 – Spring Recession under 200 cfs



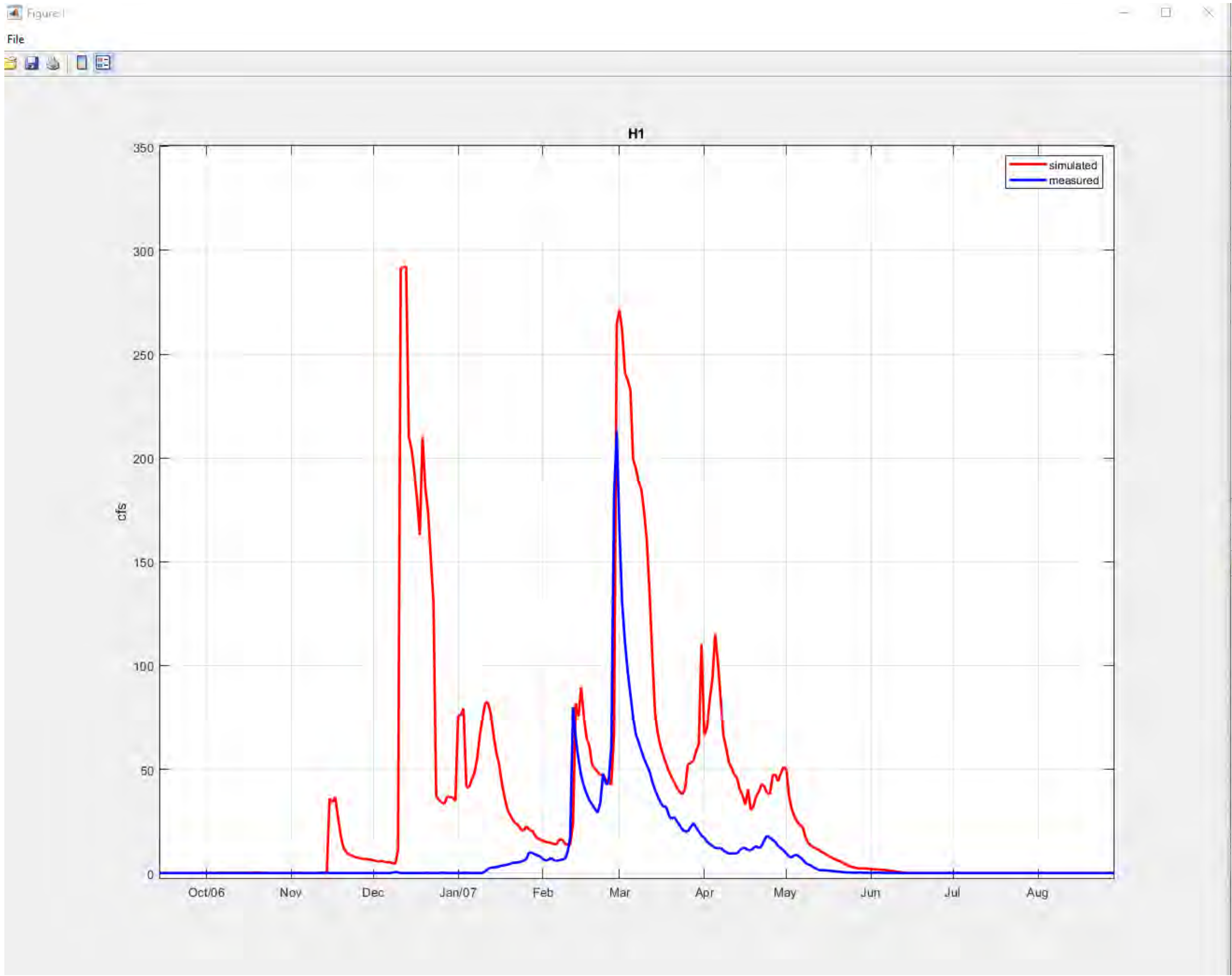


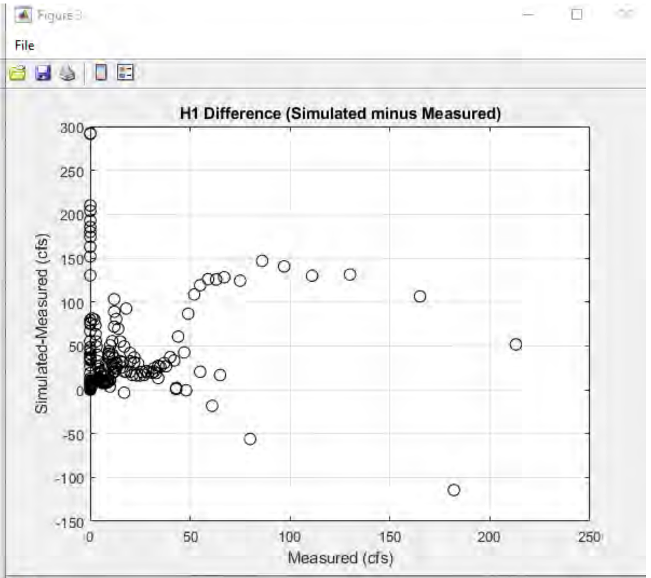


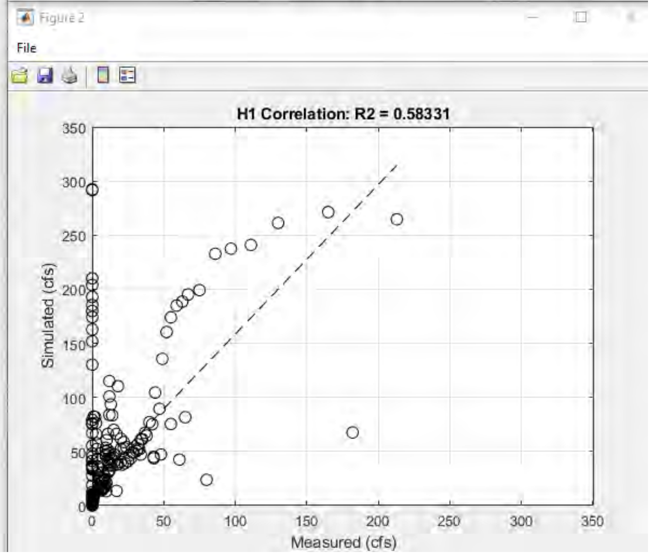
Highway One Water Year 1999 – End of Season Recession under 20 cfs



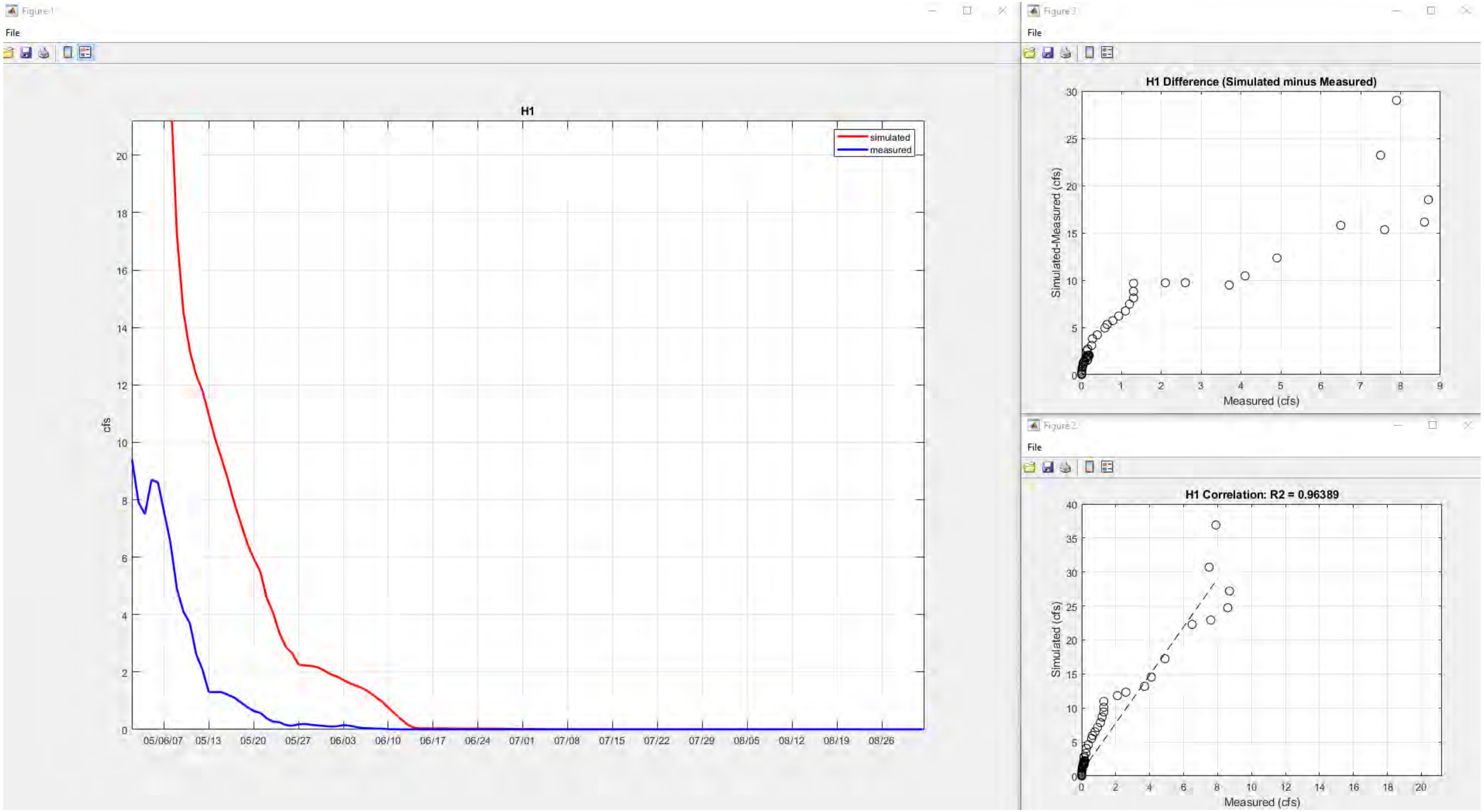
Highway One Water Year 2007







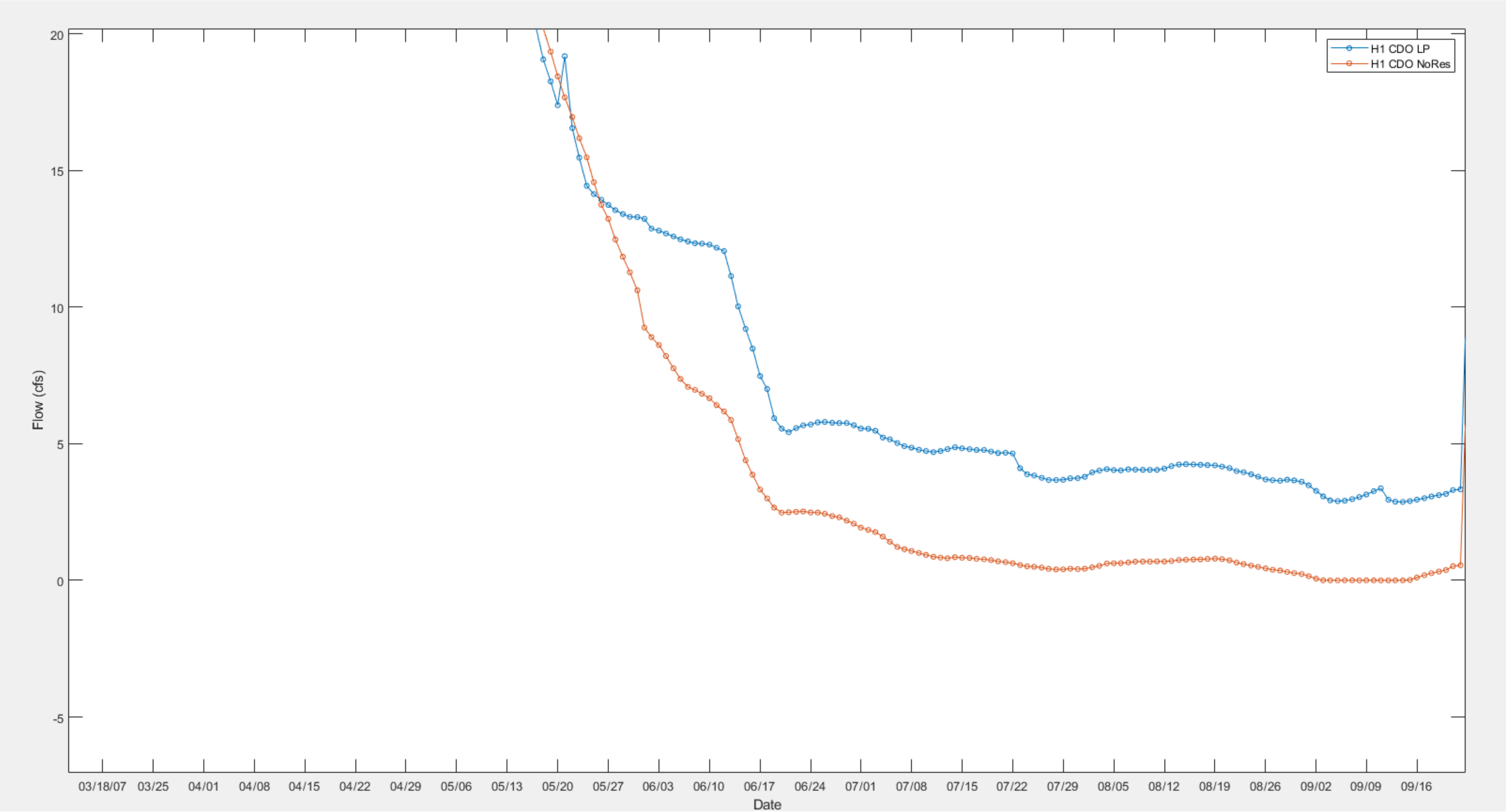
Highway One Water Year 2007 – End of Season Recession under 20 cfs



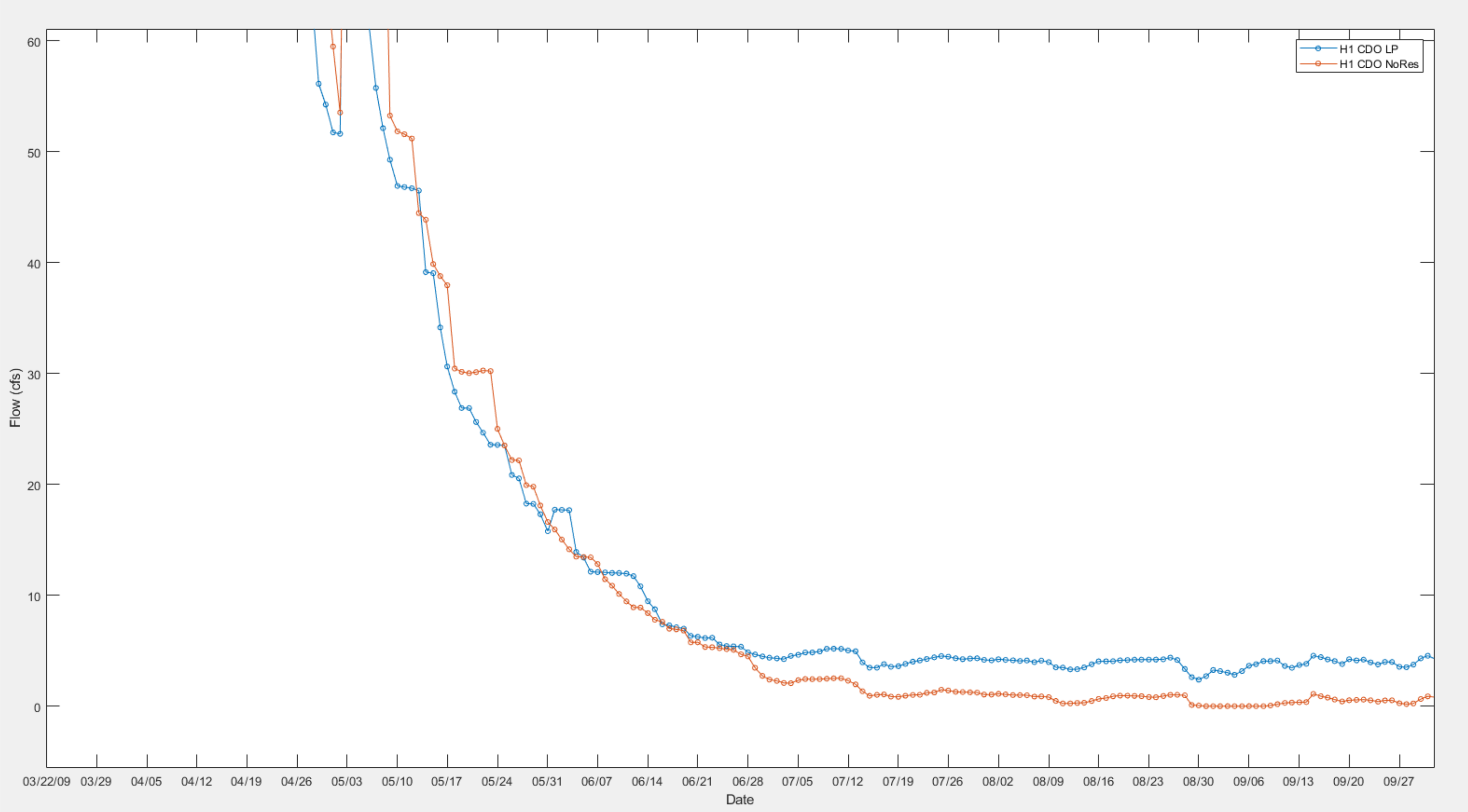
Current Scenarios in Los Padres Removal Study

- Calibrated Historic – Historic Pumping
  - Aggressive Los Padres Releases – Environmental
- Current Los Padres – CDO pumping and ASR Diversions
- Remove Los Padres – CDO pumping and ASR Diversions
- Los Padres Expanded Storage – CDO pumping and ASR Diversions
- Remove Los Padres Raise River Bed and No Pumping

Preliminary results of flows at Highway One Gage in 2007 with and without Los Padres Reservoir



Preliminary results of flows at Highway One Gage in 2009 with and without Los Padres Reservoir



Model Efficiency Conclusions

- CRBHM meets or exceeds the acceptable range(s) cited in the literature for model efficiency at all stations along the mainstem during the low flow period, despite the uncertainties introduced through spatial rainfall distribution, temporal pumping distribution, unknown reservoir operations, and the re-establishment of the riparian corridor over the model time domain.

- Monthly water budget values have a very good performance rating and represent the ability of the model to accurately simulate the watershed processes. (Moriasi, D. N.; Arnold, J. G.; Van Liew, M. W.; Bingner, R. L.; Harmel, R. D.; Veith, T. L. (2007)).

- Lower daily model efficiencies were calculated when comparing average daily flows. The lower daily NSE values do not represent a decrease in efficiency in the ability of the model to simulate changes in stresses to the system on a daily time step but are produced by the averaging of monthly pumping stresses to daily stresses.

- However even with the decrease in model efficiency associated with simulated daily flows when compared to observed, the model is within the range of acceptable uncertainty during the low flow period. (Ritter, A.; Muñoz-Carpena, R. (2013)).

- This model is a useful tool for making relative comparisons between scenarios such as the removal of Los Padres Dam or potential expansion of storage based on a dredging program or other significant changes in pumping associated with planned water resources projects in the Carmel Valley Watershed.