Water for Fish and Farms Project:

Task 4 Report
Real-Time Telemetric Streamgaging Stations

Prepared for the CALFED Bay Delta Authority Watershed Program
State of California Department of Water Resources
Contract No. 4600004701

Napa County Resource Conservation District
Paul Blank, Hydrologist

April 2010
1. Introduction

Task 4 of the *Water for Fish and Farms* project, a project of the Napa County Resource Conservation District (RCD) funded by the CALFED Watershed Grant Program, called for the establishment of six real-time telemetric streamgaging stations, two on each of three tributary creeks of the Napa River. Task 4 is divided into four sub-tasks (Sub-tasks 4.1 through 4.4). Details of the work completed under each sub-task were reported throughout the duration of the project in the monthly progress reports; however, summaries are provided in this report.

Stream stage and discharge data collected at the stations were to be reported on an annual basis, and the first annual report, submitted in October 2008, covered the period from completion of the first stations in the Fall of 2007 through September 2008. Funding for the entire project was frozen in mid-December 2008, and remained frozen through September 2009. During this period, RCD used a minimum level of separate funding to keep the streamgaging stations at a base operational level. The *Water for Fish and Farms* scope of work was not further advanced until CALFED funding resumed in October 2009. Therefore, a second annual report was not submitted in October 2009. This report summarizes all of the data collected during the grant period, including the previously unreported period of October 2008 through the present.

2. Site Reconnaissance and Selection (Sub-task 4.1)

RCD selected Carneros, Redwood, and York Creeks as the study streams based on the presence and abundance of both fish and agriculture in those subwatersheds. Upper and lower locations in each subwatershed were selected as sites for streamgaging stations. The upper stations were located in the upland reaches of each creek with year-round flow suitable for rearing of salmonids. The lower stations were located near the upland/valley floor transition where the creeks go dry and limit juvenile salmonid outmigration. The subwatersheds and streamgaging station locations are shown on Figure 1.

**Carneros Creek**
RCD established streamgaging stations on Carneros Creek under previous grants that were well located for this project. The lower station (CAO) and the upper station (CAH) would both require extensive upgrades.

**Redwood Creek**
A previously-existing gauging station, Station 02 of the Napa Valley Regional Rainfall and Stream Monitoring System (Regional Monitoring System [RMS]), was well located for the upper station. RCD would work with the local agencies associated with the RMS to facilitate an upgrade of Station 02 that would allow for measurement of low flows. RCD would establish a brand new station (RED) at the lower Redwood Creek site.
Figure 1. Streamgaging station locations.
York Creek
A previously-existing gauging station, Station 29 of the RMS, was well located for the lower station and originally was not thought to require an upgrade. RCD would establish a brand new station (YOS) at the upper York Creek site.

3. Equipment Selection, Procurement, Installation, and Programming (Sub-task 4.2)

Carneros Creek
Station CAO, the lower Carneros Creek station, was installed by RCD in 2001 with the support of local water users. As part of this project, RCD upgraded CAO with a submersible pressure transducer, new datalogger, and radio communications equipment. The equipment was programmed and calibrated and began recording high-quality low-flow stage data in February 2008. High-flow stage data from prior to February 2008 are available from RCD.

Station CAH, the upper Carneros Creek station, was installed by RCD in 2002 as part of a previous project. RCD replaced and reinstalled the submersible pressure transducer and added radio equipment for remote communications due to the high cost of installing a landline, and the absence of cellular telephone coverage. CAH is connected to CAO with a radio link, and data for both sites are obtained through a telephone landline at CAO. The equipment was programmed and calibrated and began recording high-quality low-flow stage data in February 2008.

Redwood Creek
RCD installed Station RED, the lower Redwood Creek station, in the Fall of 2007. Station RED is located at the Redwood Road bridge over Redwood Creek at the Dry Creek Road intersection. RCD selected a submersible pressure transducer as the stage sensor, a basic programmable data logger, a 12-volt solar-charged power supply, and a cellular telephone modem for remote communications due to the high cost of installing a telephone landline at the site. The equipment was programmed and calibrated and began recording stage at the start of the 2007/08 season.

RCD coordinated an upgrade of RMS Station 02 with the Napa County Flood Control and Water Conservation District and the City of Napa Public Works Department that included installation of a bubble sensor for measurement of low-flow stages. The upgrade was completed in June 2008. The equipment was programmed and calibrated and began recording stage at the start of the 2008/09 season.

York Creek
RMS Station 29, located at the Main Street (Hwy 29) bridge over York Creek, uses an ultrasonic sensor for stage measurement, a 12-volt power supply, and a radio transceiver for remote communications. It was not upgraded as part of this project.
RCD installed Station YOS, the upper York Creek station, in the Fall of 2007. Station YOS is located at a driveway bridge over York Creek on private property approximately 1.1 miles upstream of RMS Station 29 at Main Street (Hwy 29). RCD selected a submersible pressure transducer as the stage sensor, a basic programmable datalogger, a 12-volt power supply charged by 120-volt power from a nearby electric gate, and a landline telephone modem for remote communications. The equipment was programmed and calibrated and began recording stage at the start of the 2007/08 season.

4. Equipment Operation and Maintenance (Sub-task 4.3)

Throughout the duration of the project, RCD visited Stations CAO, CAH, RED, and YOS on a regular basis to clean and check the condition of equipment, replace desiccants, cut back vegetation, make repairs, and collect staff gage readings. RMS Stations 02 and 29 were maintained by other local agencies.

During winter storms and during the Spring recession of streamflows, RCD visited each site multiple times to collect discharge measurements at various stages. Several high-flow and low-flow measurements were made at each of the six sites over the course of the project.

5. Data and Data Management (Sub-task 4.4)

Stage Data
Stage data for stations CAO, CAH, RED, and YOS were collected remotely on a regular basis, checked against staff readings, viewed graphically to identify and remove anomalous data points and to identify and fill gaps, recalibrated if necessary, and stored on RCD’s server, which is backed up daily. Stage data for RMS Stations 02 and 29 are collected and stored by OneRain and are available at napa.onerain.com. RCD downloaded stage data for RMS Stations 02 and 29 on an approximate annual basis, recalibrated them to staff gage readings if necessary, and stored the adjusted data on our server. Stage data for the six stations collected during the course of this project are presented in Figures 2 through 7.

Stage-Discharge Ratings
Paired stage-discharge data were plotted and fit with a power curve to create a stage-discharge rating for each station. Stage-discharge rating curves are presented in Figures 8 through 13.

Streamflow Data
The stage-discharge ratings developed for each station were used to convert the stage record to a record of discharge (streamflow). Streamflow data for the six stations collected during the course of this project are presented in Figures 2 through 7.
Data Quality

Station CAO (Lower Carneros Creek)

Based on comparison to staff gage readings, the stage record for Station CAO is of high quality. The sensor readings are generally within 0.02 feet of the staff gage height at baseflow stages and within 0.05 feet at stormflow stages. RCD suspects that most of the difference at the higher flows is due to difficulties in accurately reading the staff gage.

RCD collected 11 measurements of discharge during the course of the project to add to the previously-existing rating curve with 22 stage-discharge pairs. The resulting rating covers a range of stages from 0.08 to 3.89 feet, a range of flows from 0.09 to 453 cfs. Interestingly, this was the only site out of the six where the points did not fit a single power curve. Instead, two curves were fit to the data, one for stages above 0.27 feet (3.10 cfs) and one for below. The flow data converted from the stage record using these curves are thought to be highly accurate.

Station CAH (Upper Carneros Creek)

Based on comparison to staff gage readings, the stage record for Station CAH is of high quality. The sensor readings are generally within 0.02 feet of the staff gage height.

RCD has constructed an excellent high-flow rating curve for Station CAH. It covers a range of 0.88 to 3.78 feet (7.90 to 429 cfs) and has an R2 value of 0.98. Flow data generated by the rating in this range are thought to be highly accurate. The rating curve currently has no points below 7.90 cfs, however. Although 11 measurements were made in this range during the 2006/07 and 2007/08 seasons, the stage was measured from an older staff gage that was located below the low-flow control of the sensor pool and could not be used on the rating curve. RCD had planned to collect more data during the 2008/09 season, but funding was frozen during that time. RCD further planned to collect these data in April 2010, but late season rains caused unfavorable flow conditions. The flow data generated from stages below 0.88 feet are of unknown quality since the high-flow curve was simply extrapolated.

Station RED (Lower Redwood Creek)

Based on comparison to staff gage readings, the stage record for Station RED is of high quality. The sensor readings are generally within 0.01 feet of the staff gage height at baseflow stages and within 0.04 feet at stormflow stages. RCD suspects that most of the difference at the higher flows is due to difficulties in accurately reading the staff gage.

RCD collected 12 measurements of discharge (0.051 to 384 cfs) over a wide range of stages (0.11 to 3.55 feet) during the project. This has resulted in a stage-discharge rating curve with an R2 value of 0.99, that will produce very good estimates of flow at all stages, given good stage data.
**RMS Station 02 (Upper Redwood Creek)**

Based on comparison to staff gage readings, the stage record for RMS Station 02 is of fair to poor quality. Recorded baseflow stages are generally within 0.1 foot of staff gage readings, but higher flow stages can be off by anywhere from 0.1 to 0.8 foot. RCD believes this is indicative of a calibration issue at the high end of the stage range which may have caused stage and flow errors at the peaks of storms. Three peaks were measured in excess of 7 feet during the past two water years that RCD would have expected to be in the 3 to 4 foot range. The flows associated with these peaks were calculated at several thousand cubic feet per second (cfs), when RCD would expect flows in the 300-500 cfs range. The target flows for this project; however, are the low flows, and in this range the data seem to be more reasonable.

RCD collected 13 measurements of discharge (0.302 to 262 cfs) over a wide range of stages (0.25 to 2.57 feet) during the project. This has resulted in a stage-discharge rating curve with an R2 value of 0.99, that will produce very good estimates of flow at all stages, given good stage data.

**RMS Station 29 (Lower York Creek)**

Based on comparison to staff gage readings, the stage record for RMS Station 29 is of fair quality. Stage values are reasonable across the range of flows, generally within 0.06 feet of staff gage readings, but temperature fluctuations have an extremely noisy record during baseflow periods. Also, sensor malfunctions have resulted in loss of data. Although unforeseen at the outset of the project, RCD has since concluded that the use of ultrasonic distance sensors is not appropriate for low-flow streamgaging.

RCD collected 19 measurements of discharge (0.29 to 292 cfs) over a wide range of stages (0.16 to 3.02 feet) during the project, to add to a set of three stage-discharge pairs that were collected after station installation the previous year. Due to site-specific challenges of obtaining precise flow measurements, the rating curve has more scatter than typical (R2 = 0.96), but it is still considered to produce good estimates of flow at all stages, given good stage data.

**Station YOS (Upper York Creek)**

Based on comparison to staff gage readings, the stage record for Station YOS is of high quality. The sensor readings are generally within 0.02 feet of the staff gage height.

RCD collected 16 measurements of discharge (0.338 to 76.9 cfs) over a wide range of stages (0.18 to 3.05 feet) during the project. This has resulted in a stage-discharge rating curve with an R2 value of 0.98, that will produce very good estimates of flow at all stages, given good stage data.
Figure 2. Streamgaging data for Station CAO (lower Carneros Creek).

Figure 3. Streamgaging Data for Station CAH (upper Carneros Creek).
Figure 4. Streamgaging data for Station RED (lower Redwood Creek).

Figure 5. Streamgaging data for RMS Station 02 (upper Redwood Creek).
Figure 6. Streamgaging data for RMS Station 29 (lower York Creek).

Figure 7. Streamgaging data for Station YOS (upper York Creek).
Figure 8. Stage-discharge rating for Station CAO (lower Carneros Creek).

\[ Q = 1294 \times (GH-e)^{4.562} \]

\[ y = 0.2079x^{0.2192} \]
\[ R^2 = 0.9001 \]

Figure 9. Stage-discharge rating for Station CAH (upper Carneros Creek)

\[ Q = 9.743 \times (GH-e)^{2.828} \]

\[ y = 0.4471x^{0.3536} \]
\[ R^2 = 0.981 \]
Figure 10. Stage discharge rating for Station RED (lower Redwood Creek).

![](image1)

\[ y = 0.3531x^{0.3944} \]

\[ R^2 = 0.9938 \]

\[ Q = 14.01 \times (GH-e)^{2.535} \]

Figure 11. Stage-discharge rating for RMS Station 02 (upper Redwood Creek).

![](image2)

\[ y = 0.4103x^{0.3324} \]

\[ R^2 = 0.992 \]

\[ Q = 14.59 \times (GH-e)^{3.008} \]
Figure 12. Stage-discharge rating for RMS Station 29 (lower York Creek).

\[ y = 0.3008x^{0.3415} \]
\[ R^2 = 0.9631 \]

\[ Q = 33.71*(GH-e)^{2.928} \]

Figure 13. Stage-discharge rating for Station YOS (upper York Creek).

\[ y = 0.33x^{0.4873} \]
\[ R^2 = 0.9777 \]

\[ Q = 9.729*(GH-e)^{2.052} \]
Water for Fish and Farms Project:
Fisheries Modeling Report

Prepared for the CALFED Bay-Delta Authority Watershed Program
State of California Department of Water Resources
Contract No. 4600004701

Napa County Resource Conservation District
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April 2010
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1. Introduction

This document reports on a modeling study carried out as part of Water for Fish and Farms, a project of the CALFED Bay-Delta Watershed Program. The aim of this project is to improve the ability of local land and water management practitioners to make informed decisions about the timing and use of water diverted from streams that support steelhead. Project activities included forming a technical and community advisory committee, installing and operating real-time telemetric stream gauging stations in selected tributaries of the Napa River, disseminating information to land/water management practitioners, and modeling hypotheses regarding streamflow and water use. The goals of these activities were to improve the timing of water withdrawals in selected tributaries of the Napa River to benefit steelhead without negatively impacting water users and to provide greater scientific understanding about the relationships between water use, stream flow, and fish habitat.

The Napa River historically supported three salmonid species: steelhead (Oncorhynchus mykiss), Chinook salmon (Oncorhynchus tshawytscha), and coho salmon (Oncorhynchus kisutch). There has been a significant decline in the distribution and abundance of steelhead in the Napa River and its tributaries since the late 1940s (USFWS 1968; Anderson 1969; Leidy et al. 2005). The U.S. Fish and Wildlife Service (1968) estimates that the Napa River watershed once supported runs of 6,000–8,000 steelhead, and 2,000–4,000 coho salmon, and that by the late 1960s, coho salmon were extinct in the watershed, and the steelhead run had reduced to about 1,000 adults. Napa River steelhead belong to the Central California Coast Steelhead Distinct Population Segment (DPS), which was listed as a threatened species under the Federal Endangered Species Act in August 1997. Current steelhead and Chinook salmon population levels are not well known but are being assessed by the Napa RCD through a smolt monitoring program, which started in 2009.

Human uses of water have been identified as a potential cause of reduction in springtime baseflow, leading to more rapid drying of the lower reaches of tributaries, and causing poor flow persistence over riffles. It has been hypothesized that these changes in stream conditions are exerting a significant influence on steelhead run size in the Napa River watershed (Stillwater Sciences, 2002; Stillwater Sciences, 2007). Reduced stream flow may impact steelhead habitat in two ways: it may reduce food availability for juveniles, thus limiting size at outmigration (which subsequently reduces survival during early ocean occupancy) and/or it may reduce the window of opportunity for steelhead to outmigrate in the spring, thus leaving steelhead either stranded in isolated pools or subject to mortality due to unsuitable dry season conditions.

Despite long-term habitat degradation and loss, the Napa River watershed still contains extensive areas of relatively high-quality steelhead and salmon habitat. In fact, it has been identified as one of the most important anchor watersheds within the San Francisco Estuary for the protection and recovery of regional steelhead populations (Becker et al. 2007). The fisheries modeling component of this project focused on two streams known to contain high-quality steelhead habitat in their upper reaches: Carneros Creek and Redwood Creek (Figure 1). Carneros Creek was habitat-typed in 2002 by the Napa RCD as part of a watershed assessment, and Redwood Creek was habitat-typed by the Napa RCD in 2007 with funding from the Department of Fish and Game.
Figure 1. Napa River Watershed map showing the Carneros and Redwood Creek study sites.
2. Physical Habitat Model

The Physical Habitat Simulation System (PHABSIM) model was developed by the US Fish and Wildlife Service, US Geological Survey, and other agencies to examine stream flow management issues as part of the Instream Flow Incremental Methodology (IFIM). PHABSIM predicts physical microhabitat changes associated with flow alterations such as a reduction in stream flow. It also provides a variety of simulation tools, which characterize the physical microhabitat structure of a stream and describe the flow-dependent characteristics of physical habitat relative to selected target species and life stages. When interpreting PHABSIM results, an assumption is normally made that flow-dependent physical microhabitats are useful in determining carrying capacity and therefore are related to the instream flow needs or impacts of flow variations on fish or other aquatic organisms in streams (USGS, 2001).

For this project, we used PHABSIM to simulate habitat conditions for juvenile steelhead during low flow conditions that are typical of tributary streams in spring and early summer. Based on historical flow records, we determined that this included flows from zero to 20 cubic feet per second (cfs). The spring growth season, which extends from approximately March through July, has been identified as an important period for juvenile steelhead growth as well as smolt outmigration (Stillwater Sciences, 2007; Koehler, 2009). The results of the PHABSIM models were intended to identify important flow thresholds for juvenile steelhead during this critical period and ultimately share this information with water users to help guide their water diversion practices.

3. Carneros Creek

Carneros Creek is a tributary to the Napa River, which flows from the west side of the Napa Valley into the Napa River near Cuttings Wharf and Bull Island, 8 km (5 mi) south of the town center of Napa (Figure 2). Carneros Creek has a drainage area of 23.0 km² (8.9 mi²). The highest elevation in the watershed is approximately 506 m (1,660 ft), while the confluence with the Napa River is at mean sea level and is tidally influenced. The lowest 500 m (1,640 ft) of the creek is confined within levees designed to control flooding of the Napa River. Carneros Creek is a third order stream, with a total channel length of approximately 17.9 km (11.1 mi). The predominant land cover types in the Carneros Creek watershed are grassland and mixed oak woodland.
Figure 2. Carneros Creek watershed map showing the location of the PHABSIM study reach.
A. Carneros Model Input Data

A total of nine transects were surveyed in Carneros Creek (Figure 2). Each transect was surveyed using a Theodolite and stadia rod according to the methodology outlined in the PHABSIM User’s Manual (USGS, 2001). Three transects were located in run habitat types, three were located in riffle habitat types, and three were located in pool habitat types. The exact transect locations were determined by using existing habitat typing data to stratify the study reach into three major habitat categories: Pools, Riffles, and Runs. We then measured the full length of each potential unit and randomly selected a position to establish the cross-section.

We measured water surface levels (WSL) with a Theodolite and stadia rod at all transects at the three target flows listed in Table 1. Water velocities were measured during the medium flow using USGS current meters and wading equipment.

<table>
<thead>
<tr>
<th>Date Discharge (cfs)</th>
<th>WSL Measured</th>
<th>Velocities Measured</th>
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<td>February 4, 2008</td>
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Table 1. Summary of PHABSIM field measurements on Carneros Creek

There are several published juvenile steelhead Habitat Suitability Criteria Curves (HSC) for water velocity and depth. We selected the Bovee 1978 HSC based on extensive literature review, consultation with Stillwater Sciences, and input from the Technical Advisory Committee. Overall, we felt the two curves developed by the Bovee 1978 study were most appropriate for our analysis because of similarities in watershed areas, stream size, and target species. Both curves are shown in Appendix B.

In addition to the three calibration flows, the PHABSIM model was setup to run simulations for 0.5, 1.0, 5.0, and 20.0 cfs.

B. Carneros Model Calibration

The PHABSIM model was calibrated by comparing simulated and observed results for the three known flows. Plots of simulated velocity and water surface elevation were visually analyzed for consistency. Transects with poor agreement between simulated and observed values were adjusted manually using Manning’s n values and discharge estimates as described in the PHABSIM users manual.

Model calibration results are listed in Table 2.
Table 2. Carneros Creek PHABSIM model calibration results showing observed (obs) and simulated (sim) water surface levels (wsl) and the difference between the two values (diff) at all nine transects. All values are in feet.

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<th>2.02 cfs sim wsl</th>
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C. Carneros Model Results

The Carneros Creek PHABSIM model results are shown in the form of a Weighted Usable Area (WUA) curve (Figure 3). The model produces quantitative estimates of total habitat area over the full range of flows, however it is generally considered more accurate to assess the shape of the WUA curve rather than the specific numeric results. In light of this, we analyzed the WUA curve for breaks in slope, which are believed to represent flow thresholds for juvenile steelhead. Two best-fit trend lines were added to the graph to help identify slope breaks.

PHABSIM model results suggest that there are distinct flow thresholds for juvenile steelhead within our study reach in Carneros Creek. The first is apparent at approximately two cfs where the curve is steepest. The second threshold appears at approximately five cfs, where there is a notable break in slope and generally flattening out of the curve. It is also interesting to note that the amount of juvenile steelhead habitat appears to level off at flows above approximately 14 cfs. Although juvenile habitat does not improve much above 14 cfs, these higher flows are important for maintaining habitat complexity, adult fish passage, and spawning.
Figure 3. Weighted usable area (WUA) curve with trend lines for Carneros Creek.

4. Redwood Creek

Redwood Creek is a tributary to Napa Creek, which flows from the west side of the Napa Valley into the Napa River near the town center of Napa (Figure 4). Redwood Creek has a drainage area of 19.58 km² (7.56 mi²). The highest elevation in the watershed is approximately 506 m (2,600 ft), while the confluence with Napa Creek is at approximately 15 m (50 ft) above mean sea level. Redwood Creek is a third order stream and has approximately 30.3 km (18.8 mi) of blue line stream according to the USGS Napa and Sonoma 7.5 minute quadrangles. Mixed hardwood and conifer forest dominate the watershed with extensive redwood groves in the middle and upper watershed. The watershed is almost entirely privately owned; much of the headwaters are held by the Napa County Land Trust. Vehicle access in the middle and upper watershed exists via Redwood Road.
A. Redwood Model Input Data

A total of nine transects were surveyed in Redwood Creek. Each transect was surveyed using a Theodolite and stadia rod according to the methodology outlined in the PHABSIM User’s Manual (USGS, 2001). Three transects were located in run habitat types, three were located in riffle habitat types, and three were located in pool habitat types. The exact transect locations were determined by using existing habitat typing data to stratify the study reach into three major habitat categories: Pools, Riffles, and Runs. We then measured the full length of each potential unit and randomly selected a position to establish the cross-section.

We measured water surface levels (WSL) with a Theodolite and stadia rod at all transects at the three target flows listed in Table 3. Water velocities were measured during the medium flow using USGS current meters and wading equipment.

<table>
<thead>
<tr>
<th>Date</th>
<th>Discharge (cfs)</th>
<th>WSL Measured</th>
<th>Velocities Measured</th>
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<td>March 9, 2010</td>
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</table>

Table 3. Summary of PHABSIM field measurements on Redwood Creek

There are several published juvenile steelhead Habitat Suitability Criteria Curves (HSC) for water velocity and depth. We selected the Bovee 1978 HSC based on extensive literature review, consultation with Stillwater Sciences, and input from the Technical Advisory Committee. Overall, we felt the two curves developed by the Bovee 1978 study were most appropriate for our analysis because of similarities in watershed areas, stream size, and target species. Both curves are shown in Appendix B.

In addition to the three calibration flows, the PHABSIM model was setup to run simulations for 0.5, 1.0, 9.0, 16.0, and 20.0 cfs.
Figure 4. Redwood Creek watershed map showing the location of the PHABSIM study reach
B. Redwood Model Calibration

The Redwood Creek PHABSIM model was calibrated by comparing simulated and observed results for the three known flows. Plots of simulated velocity and water surface elevation were visually analyzed for consistency. Transects with poor agreement between simulated and observed values were adjusted manually using Manning’s n values and discharge estimates as described in the PHABSIM users manual.

Redwood Creek model calibration results are listed in Table 4.

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Table 4. Redwood Creek PHABSIM model calibration results showing observed (obs) and simulated (sim) water surface levels (wsl) and the difference between the two values (diff) at all nine transects. All values are in feet.

C. Redwood Model Results

The Redwood Creek PHABSIM model results are shown in the form of a Weighted Usable Area (WUA) curve (Figure 5). The model produces quantitative estimates of total habitat area over the full range of flows, however it is generally considered more accurate to assess the shape of the WUA curve rather than the specific numeric results. In light of this, we analyzed the WUA curve for breaks in slope, which are believed to represent flow thresholds for juvenile steelhead. Two best-fit trend lines were added to the graph to help identify slope breaks.
Redwood Creek PHABSIM model results suggest that there were distinct flow thresholds for juvenile steelhead within our study reach. The first is apparent at approximately three cfs where the curve is steepest. The second threshold appears at approximately six cfs, where there is a notable break in slope. Unlike our results for Carneros Creek, there was a less pronounced leveling off at higher flows. However, the curve is relatively flat above approximately 16 cfs, and flows above this level would not be expected to generate much additional juvenile steelhead habitat. As described for Carneros, these higher flows are important for other biological and geomorphic functions besides juvenile rearing.

Figure 5. Weighted usable area (WUA) curve with trend lines for Redwood Creek.
5. Conclusions and Recommendations

Results from the PHABSIM model suggest that there are distinct flow thresholds for juvenile steelhead in both creeks. For Carneros Creek, the amount of juvenile habitat sharply decreased below five cfs. The model also suggests that very little juvenile habitat value is gained at flows above 14 cfs. Therefore, within our study reach on Carneros Creek, we conclude that flows below five cfs are the most important for supporting juvenile steelhead.

For Redwood Creek, the amount of juvenile steelhead habitat sharply decreased below six cfs. The Redwood model showed a less distinct leveling off trend at higher flows, but our results do suggest that flows above 16 cfs contribute little habitat value for juvenile steelhead. Therefore, within our study reach on Redwood Creek, we conclude that flows below six cfs are the most important for supporting juvenile steelhead.

Model results also suggest that the largest habitat gain for juvenile steelhead occurred at the lowest flows in both creeks. For Carneros Creek, the WUA curve was steepest between zero and two cfs. For Redwood Creek, the WUA curve was steepest between zero and three cfs. Our results suggest that flows below these low flow thresholds are especially critical for juvenile steelhead. We would expect that even relatively small diversions under such conditions would have a significant negative effect on steelhead habitat.

Acknowledgments

NCRCD is grateful to the many agricultural water diverters on Carneros and Redwood Creeks who contributed information on their diversion and irrigation practices, and to the Napa County Conservation, Development and Planning Department for assistance in transferring information from the regional model to the project and with other data needs. We would also like to thank the private landowners along both creeks that granted us access to their properties for the duration of this study.

Principal funding for the project came from the CALFED Bay-Delta Watershed Program, with matching funding from a variety of local sources.
References


Appendices

A. Site Photos

Redwood Creek, 3.12 cfs, 1/14/2010

Redwood Creek, 6.03 cfs, 2/2/2010
Redwood Creek, 12.56 cfs, 3/9/2010

Carneros Creek, 8.33 cfs, 2/27/2008
Carneros Creek, 13.90 cfs, 2/4/2008
B. Habitat Suitability Criteria Curves

Based on data from Bovee, 1978
Water for Fish and Farms Project:
Hydrologic Modeling Report

prepared for the CALFED Bay-Delta Authority Watershed Program
State of California Department of Water Resources
Contract No. 460004701

Napa County Resource Conservation District
Robert Zlomke, P.E.
DHI Water & Environment
O’Connor Environmental

April 2010
1. Introduction

This document reports on a modeling study carried out as part of *Water for Fish and Farms*, a project of the CALFED Bay-Delta Watershed Program. The aim of this project is to improve the ability of local land and water management practitioners to make informed decisions about the timing and use of water diverted from streams that support steelhead and/or Chinook salmon. Project activities included forming a technical and community advisory committee, installing and operating real-time telemetric stream gaging stations in selected tributaries of the Napa River, disseminating information to land/water management practitioners, and modeling management alternatives regarding streamflow and water use. The goals of these activities were to improve the timing of water withdrawals in selected tributaries of the Napa River to benefit steelhead and/or Chinook salmon, without negatively impacting water users, and to provide greater scientific understanding about the relationships between water use and stream flow. The hydraulic modeling efforts described in this report were conceived as an extension and expansion of recent baseline hydrologic modeling assessments, which were done for Napa County as part of the recent *Napa County Baseline Data Report* (Jones & Stokes et al., 2005, hereafter referred to as *BDR*).

Various tributaries of the Napa River, like the main stem of the river itself, provide water for agricultural or other rural use by direct diversion. These diversions are governed by water right licenses and permits and are generally concentrated during the rainy season, which begins in December and runs roughly through the end of March in most years. However, in some cases there may be diversions later in the spring as well. The season of diversion is normally specified in the license or permit which governs a particular water right, along with other restrictions – notably a required bypass flow. However, water diverters enjoy some flexibility over when to divert within the permit-specified diversion season.

The flow in these tributaries is also important to the well-being of aquatic species, notably threatened steelhead and other salmonids. A study for the San Francisco Bay Regional Water Quality Control Board found channel drying in the spring and summer to be a possible hindrance to the migration of salmonids (Stillwater Sciences, 2002). It seems evident that the timing of water diversions, particularly their presence or absence during the period of springtime flow recession, is important to aquatic life. This modeling study aimed to investigate the timing of water diversions on selected tributaries and explore possible variations in timing that might be beneficial to fish.

The *BDR* offered a useful technical tool to pursue this issue. On the basis of the MIKE SHE/MIKE 11 software developed by DHI Water & Environment, Inc. (DHI), the *BDR* developed integrated surface and ground water models for the Napa River watershed and the other watersheds of Napa County. The MIKE SHE/MIKE11 model is a physically based, distributed hydrologic model, which simulates the major flow components of the hydrologic cycle. Results are available for all the major flow components of the hydrologic cycle, including stream hydrographs and water surface profiles. The model is also scalable; the initial model, which may be thought of as a *regional* model in comparison to the more local focus of the present project, lends itself readily to more focused analysis with the addition of more spatially detailed data.
This project focused on developing local models of individual tributary watersheds within the larger Napa River watershed, on the basis of this regional model. These modeling projects accompanied a project effort to establish stream gaging stations on Napa River tributaries with anadromous fish habitat value and potentially limiting water flow. Staff from Napa County Resource Conservation District (NCRCDD) selected three Napa River tributaries for these gaging stations: Carneros, Redwood and York Creeks. The initial modeling plan was to develop an integrated surface and ground water model for each of the three creeks, on the basis of the regional model described above, and use it to investigate the timing of springtime water diversions. However, lessons learned from the first model (Carneros) led us to modify that plan. In the end, two rather than three tributary models were developed, one for Carneros and one for Redwood. This change of plan is further described in the section on the Carneros model below.

Project work was halted by the State in December 2008, at which point the Carneros modeling work was complete and the Redwood model was still under construction. The project was suspended for approximately a year from that point, which has made for some difficulties. However, the NCRCDD was able to reassemble the project team, with only a couple of changes of affiliation, and the modeling work was brought to the conclusion represented by this report. However, the long break in the work made it difficult to pull together all the strands of the two modeling efforts, so that some of the details one would normally expect in a report like this were no longer available. This report represents our best effort to report faithfully what was done.
Figure 1. *Water for Fish & Farms* Study Creeks in the Napa River Watershed
2. MIKE SHE Model

The MIKE SHE/MIKE 11 software is a hydrologic model that includes all the major elements of the land-based portion of the hydrologic cycle, excluding only atmospheric processes. This combined package is noteworthy for including hydraulic modules for both surface and ground water processes, and for representing all of the hydrologic processes using techniques that are both physically-based and distributed. That is, the underlying equations are based on physical laws with parameters that can be quantified by measured data, and the model allows for the distribution of model parameters and results in both space and time. The model may be contrasted, on the one hand, with models based on empirical relationships, for which it is difficult to estimate site-specific input parameter values; or on the other hand with lumped models, which do not model the natural local variations in important parameters.

To take one example, this effort modeled flow in the unsaturated zone as depending on a set of measured parameters that vary with soil type – such as water content at saturation or at wilting point – and these parameters are allowed to vary spatially throughout the modeled area. This is accomplished by defining a model grid in the horizontal plane and allowing model parameters to vary from one grid cell to the next. A grid-based model like MIKE SHE can be used for a wide variety of different situations by varying the grid cell size, if data are available to realistically support the scale desired. For the present project, the 250 m (820 ft) grid cell size used for the regional model of the Napa River watershed was reduced to 200 ft or less for the local models developed for Carneros and Redwood Creeks. For many input parameters, the data sources for the regional model could be used again for these local models.

The local MIKE SHE models used the following major model components: evapotranspiration, overland flow, channel flow, unsaturated zone flow, and saturated zone flow. Brief information on the handling of each of these components follows.

- **Overland Flow:** *Finite difference method.* MIKE SHE has two options, and this is the more complex of the two. It uses an explicit two-dimensional diffusive wave approximation of the St. Venant equations, and the principal parameter is the Manning number.
- **Channel Flow:** *MIKE 11 high order fully dynamic.* This is the most complete form of the St. Venant equations available in the model.
- **Unsaturated Zone:** *Two-layer water balance method.* This is the least complex representation of flow in the unsaturated zone, relying on a simple mass balance approach. It uses the soil parameters mentioned earlier to estimate the storage capacity of the soil, the amount of water available for transpiration in the root zone, and the amount of groundwater recharge.
- **Saturated Zone:** *Finite difference method.* This is more complex than the alternate linear reservoir method, and it was chosen because it permits a more detailed representation of the spatial variation of groundwater characteristics and of the interaction between surface water and groundwater.
Various aspects of the handling of these components in the two local models will be discussed below in the descriptions of model input data and construction. Further information may be found in the *BDR Technical Appendix*, which discusses their application in the regional model (DHI, 2005).

### 3. Carneros Creek

The Carneros Creek model was begun first, because NCRCD had flow data for this creek at three gaging stations established under previous funding, so that there were calibration data available immediately.

A hydraulic model was constructed for the Carneros Creek watershed using the MIKE SHE model. This was a finer-resolution version of the regional model developed for the Napa River watershed as a whole for the BDR. This Carneros model was constructed by NCRCD staff with the collaboration of DHI. The model domain included the Carneros Creek watershed area upstream of the Old Sonoma Road bridge, or about two-thirds of the full watershed. Carneros Creek drains into the Napa River near Cuttings Wharf. The model domain ended just below the bridge because the creek reach immediately upstream of the bridge has a notable concentration of creek diversions, and because the most downstream of the NCRCD gaging stations on Carneros Creek is located at this bridge.

#### A. Model Input Data

Input data were derived from the same County GIS sources as the regional model and re-processed for a new model grid of 100 ft, as opposed to 250 m (820 ft) in the regional model. The data source for topography was the LiDAR dataset maintained by Napa County, which was also the initial source of information on channel cross sections. NCRCD surveyed several cross sections for comparison with the LiDAR cross sections, and the latter were adjusted to agree with the surveyed sections. Cross sections collected by others were used to provide an additional comparison.

Rainfall data were obtained from 5 stations in the system maintained by Agri-link, Inc. Some gap filling was required. The measured rainfall was assigned spatially using elevation-modified Thiessen Polygons. The stations are listed in Table 1. Evapotranspiration was modeled using reference evapotranspiration data from the California Irrigation Management Information System (CIMIS) record at nearby site 109, also in the Carneros region.
Table 1. Carneros rainfall data

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Flow data for calibration of the model were available at stations CAO (Carneros Creek at Old Sonoma Road) and CAH (Carneros Creek at Henry Road) for most of water years 2002-06. These stations were established and rated for discharge under previous projects, but both were identified as key locations for fish and were studied in detail under the present project: Station CAO for adult fish passage, and CAH for rearing habitat. The locations of stations CAO and CAH are shown in Figure 2. There were issues with the low-flow portions of these records, which will be discussed under Model Sensitivity and Calibration below.

The saturated zone was modeled using essentially the same information as in the regional model. There was one basic saturated zone layer, with two aquifer lenses carried over from the regional model, the Huichica and Alluvial aquifers. There was virtually no borehole data available for the tributary watersheds, so a significant degree of uncertainty is associated with the groundwater component of the model. Rural domestic pumping was modeled exactly as in the regional model, using the same database of well data and the same average rates obtained from the County, although in the course of model construction the wells were deepened to make sure they were able to pump most of the specified demand. Land use, vegetation, and soils data were derived from the same County GIS sources as the regional model and re-processed for the 100-ft model grid.

Irrigation was modeled in a more complex manner than in the regional model. There is considerable use of surface water for irrigation of vineyards in the Carneros Creek watershed. NCRCD investigated this use and built the results into the model.

B. Model Construction

Since the Water for Fish and Farms project is focused on water use, considerable time was invested in researching water rights on Carneros Creek. There were a number of surface water rights in the model domain, including eight farmers with the right to pump from the creek to off-channel storage. Of the 1046 acres of vineyards in the model domain, approximately 783 acres were farmed by these eight diverters. NCRCD interviewed most of these diverters and obtained information on their diversion and irrigation practices. Two irrigation command areas for vineyards were defined in the model, one using water diverted from the creek, for these 783 acres, and one
fed by groundwater pumping, for the remainder. Total irrigation demand was estimated at 0.30 ac-ft/ac for all vineyards in the model domain.

In fact, a portion of the irrigation demand that is met by surface water sources comes from water trapped and stored in reservoirs off the main channel. It was not feasible to represent these features at the scale of the model, so the reduction in streamflow represented by reservoir capture was estimated as the difference between the total irrigation demand (for the 783 acres irrigated by surface water) and the available streamflow for diversion, and then subtracted from the precipitation inputs.

For the eight creek diverters, time series of pumping flow rates were constructed from the NCRCD’s observed flow record at Old Sonoma Road, on the basis of detailed interviews with water users. The information gained from the interviews was that they typically start pumping some six hours after the peak of a storm, in order to avoid the silt-laden water characteristic of the rising limb and peak of storms, and continue until the flow drops down to the level at which they are required to stop pumping. This bypass flow level is set at 10 ft$^3$/s for most diverters. These time series of pumping used the rate of diversion specified in the water rights, which was verified with the water users as well. In the model, periods of pumping less than twelve hours were neglected, and pumping was not generally started during the night.

Three water users have a right to pump from the creek in the spring for frost protection purposes, but conversations with two of them and other knowledgeable sources indicate that these water users actually withdraw the water earlier, during the rainy season when water is plentiful, rather than wait till the spring when creek flow is often low. All three have facilities for storing water. A review of springtime flow records found no indication of springtime pumping for frost protection, although the records reviewed were admittedly somewhat questionable at low flow.

There is one golf course (Vineyard Knolls) within the model domain; the irrigation demand for this facility was set at 4 ac-ft/ac/yr, or a constant value of 0.1392 mm/h (0.00548 in./hr), on the basis of a recent local study (West Yost, 2005).

C. Model Sensitivity & Calibration

The model was calibrated for the four-year period from August 2002 to August 2006, using the rainfall data and NCRCD streamgaging records for this period. After verifying that the modeled water balance was approximately consistent with previous results from the regional model, the next step was to calibrate the model. Because the focus of the project was springtime flows, the calibration focused on two primary metrics: the magnitude of peak flows during the spring and the overall flow record during the period from the last storm through the cessation of flow. Each of these was captured by a quantitative measure.

The peak calibration considered all peaks after March 1 each year that exceeded a specific threshold in the measured record (50 ft$^3$/s at Old Sonoma Road), up to a maximum of three per
year. This threshold value was chosen to capture a representative sample of springtime flow peaks. Modeled flows were compared with hourly flow values from the measured record (which were derived by averaging values in the original 15-minute record). The mean absolute error (MAE) was calculated as the absolute value of the modeled residual (the difference between the measured and modeled values) for each storm, taking the mean of these values. To make it a unitless quantity, the MAE was then expressed as the ratio of this mean absolute difference to the mean of the measured values.

The overall springtime flow calibration was complicated by issues with the observed records. One important result of the present project was the discovery that the low-flow portions of the flow records for these stations were not reliable; considerable effort under a different project task was expended to improve these. The flow record at station CAO was considered unreliable at low flows, because it was obtained using an ultrasonic sensor that produces noisy data at low flows. At CAH, there was a pressure transducer, so that the low-flow data were more plausible, but the low-flow portion of the rating curve at this site had not received close attention before the Water for Fish and Farms project, so that the accuracy of these values was not well established. Springtime records at station CAH were essentially complete through the cessation of flow for two of the four years modeled.

At station CAH, the calibration used the data for the spring of 2004 and 2006 which were available in NCRCD final data records for those years. At CAO, the measured record was adjusted by linear interpolation between the last storm and the date of cessation of flow (as noted by a local observer). Because of uncertainty associated with the record at CAO, the calibration at CAH was given more weight than that at CAO. As with the peak calibration, the calibration used a metric which took the ratio of the mean of the absolute values of modeled residuals to the mean of the measured values (as adjusted, in the case of station CAO).

A further issue arose in the course of calibration: because the recession limbs in the immediate aftermath of storms dropped off more quickly in the model than in the measured record, the flow sometimes fell to a level that prevented scheduled creek pumping from taking place, and the model which best matched springtime peaks and the overall springtime recession – as measured by the calibration metrics just defined – prevented a significant amount of diversion from the creek from happening. In fact, the total amount diverted from the creek was less than half the intended volume. Since this phenomenon is important to the project and was modeled with considerable care, it seemed important to minimize the shortfall.

The final calibration of the model reduces the shortfall to about 16% of the intended volume. This was achieved by implementing drainage at a depth of 0.610 m (2 ft) in the vineyard areas and lowering the hydraulic conductivity in the alluvial aquifer. There is drainage present in many of the vineyards, and the change in hydraulic conductivity was considered to be reasonable. Together, these changes had the effect of strengthening the recession limbs in the immediate aftermath of storms. The sensitivity of the model to changes in a number of other modeling parameters was
also examined; parameter modifications to which the model did not appear to be very sensitive included the following:

- varying the infiltration properties of soils
- variation in the roughness coefficient for either overland flow or channel flow
- adjustment to the hydraulic conductivity in the relatively slow Huichica aquifer

The final calibration metrics are shown for both calibration points CAH and CAO in Table 2, along with the ratio of mean error to the observed values. The results for spring 2004 at CAH are shown in Figure 3, along with the observed record for that period. The calibration metrics are reasonably close for the peaks; the ratio of the MAE to the mean of the observed values varies from 21% at CAH to 29% at CAO. If absolute values are not used, the departure is less, and at station CAH (where the calibration data are more reliable) the agreement between modeled and observed values is better than at CAO. At both sites, the model overpredicts peaks somewhat, as shown by the mean error ratios. Given that the main interest of the model is to capture springtime low flows, the peak flow calibration is more than adequate.

The overall calibration is less satisfactory. As was mentioned above, the model tended to make the recession limbs of the hydrograph drop off too quickly compared to the observed record, and an effort was made to minimize this in order to better represent the hydrographs in the model and allow for the pumping from the creek to happen as intended. This had the effect of slightly raising the slow seasonal recession, which was already higher than the observed. Figure 3 illustrates the general situation. At the left edge of the graph, which is right after the last storm peak of the year, the modeled discharge is already low, but over the course of the spring it declines more slowly than the observed record does. As the figure illustrates, the overprediction of flow in the model increases over time, and by the end of the observed record on April 30 the simulated flow is twice as great as the observed. Flow during the two small runoff events in the figure is overpredicted as well.

The difficulties encountered during the calibration can be summarized as a lack of adequate representation of the interflow component of the hydrograph in the model, so that the recession limb declines too rapidly, and a systematic over-prediction of baseflow. The overall volume error is rather large, and this should be borne in mind in interpreting any scenarios run with the model.

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Figure 2. Carneros and Redwood Creek Watersheds with Gaging Stations
D. Model Applications

The calibrated model was used to study the following scenarios:

- **Scenario 1: No pumping at all.** This scenario assumes that all creek pumping ceases, without providing any alternate water source. The purpose is to quantify roughly the effect of current practices.

- **Scenario 2: Springtime pumping.** This scenario assumes that water users with a right to springtime pumping actually pump all water used for frost protection in the spring. This is contrary to their current practice, which is to pump to storage during the winter.

- **Scenario 3: Extra winter pumping for springtime release.** This scenario posits additional pumping during the normal diversion season by 2 water users, after the amount required for irrigation has already been pumped. The additional water is stored for release later in the spring, to augment springtime flows.
Scenario 1 addresses the natural question of the effect of current practices on creek flow. Looking at the results for the two years of most average rainfall (2003-04 is slightly below average, 2002-03 slightly above), the effect of the onset of pumping is clearly visible in the calibrated model as opposed to the scenario. In fact, the scenario is smoother and better matches the observed record, which unlike the calibrated model does not show the effects of pumping. We have not found any sign of pumping starting or stopping in the observed record at CAO, which indicates that the current pumping practices of creek diverters spread out the effects of starting and stopping, so that sudden variations in flow are avoided. The sudden drops in the flow at the onset of pumping are purely a consequence of the model setup, in which all diverters start at once when conditions are favorable and stop at once when flow becomes too low.

Figure 4 shows the results for 2003-04, a below-average rainfall year, for both stations. The effects of pumping are shown by comparing the base case, in black, with Scenario 1, in red. The differences are most clearly seen at CAO, which lies downstream of all modeled creek diversions. Some pumping occurs on the recession limb for each of the storms shown in the figure, but the scenario 1 hydrograph rejoins the baseline hydrograph when the discharge at CAO reaches the level of the required minimum bypass, 10 ft³/s. The effect of the model setup, which has everyone pumping on the same schedule, is to make the baseline hydrograph rejoin the scenario 1 hydrograph in a much more abrupt manner than actually happens in reality, as shown by the observed (blue) line. Interpretation of these results is complicated by the fact that the difference between the modeled and observed discharges is so large compared to the simulated effects of this scenario.
Scenario 2 implements springtime pumping for frost protection at two points of diversion located upstream of CAO, within a half mile of Old Sonoma Road. The effects of this pumping are translated almost immediately into a reduced discharge at station CAO. The reduction in flow at CAO is virtually equal to the sum of the two pumping rates and is not shown. It is interesting to note the time lag between the onset of pumping and the full reduction in discharge at CAO, which is illustrated in Figure 5 for the same year of below-average rainfall, 2003-04. The figure shows the rate of pumping at one point of diversion (there are two) ramping up from zero to the full amount over one 15-minute time step; the effect of this change on the flow downstream at CAO takes approximately two hours to register fully. A similar result is visible in the model when pumping stops. It should be mentioned that this scenario if implemented in actual fact would result in return flows to the creek, which are not modeled in the scenario as constructed.

As one would expect, Scenario 2 shows some restoration of wintertime recession flows because of the foregone pumping. This is visible at both calibration points CAH and CAO, but especially at
CAO, which is downstream of these activities. The restoration of these wintertime flows, however, is not likely to be as important for habitat improvement as the reduction in springtime flows is detrimental.

Figure 5. Hypothetical Direct Diversion for Frost Protection, 2004, CAO, ft$^3$/s

<table>
<thead>
<tr>
<th>Black = base case at CAO</th>
<th>Red = Altered flow at CAO under Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple = frost protection pumping at point of diversion upstream (shown as negative)</td>
<td></td>
</tr>
</tbody>
</table>

Scenario 3 is set up to pump a hypothetical total of 20 ac-ft extra per year, 10 ac-ft each at two existing points of diversion upstream of station CAH, for release to the stream in late spring. Setting aside for the moment the practical obstacles to this, it is assumed that the existing diversions are prolonged during winter storms to pump the additional volumes required and that storage is available until late spring, when the water can be returned to the creek at a slower rate without adversely affecting water temperatures. The scenario takes a first cut at evaluating the possible advantages and disadvantages of the idea.

Figure 6a shows the effect of the additional pumping required during the winter high-flow season for a year of above-average rainfall, 2005, at station CAH, where the potential improvement in fish habitat would be experienced. The extended pumping required under this scenario starts in the lefthand part of the figure and continues after the peak, until the required minimum bypass of 10
ft³/s is reached. Under the scenario, the reduction in flow exhibited during this storm persists through several more storms than would otherwise be the case.

In Figure 6b, the effect of release of the water is indicated. The extra volume of water is returned to the creek at a rate of 0.125 ft³/s over a period of approximately 40 days. For the spring of 2005 the period modeled ran from May 8 through June 17. The figure shows the flow relationships over a two-day period at the end of return inflow. There does not seem to be any potential issue of abruptness in the response of the creek to the cessation of the inflow.
The development of the Carneros model, with its detailed representation of surface water diversion practices in the reach upstream of Old Sonoma Road, has led to the conclusion that the timing of current diversions is not likely to harm fish. Scenario 1, which removes all diversions from the creek, shows no effect outside the winter high-flow season for any of the 4 years modeled. Of course, this conclusion is not surprising, since interviews with water users led to the construction of diversion schedules that concentrated the pumping during the times of relatively silt-free flow during the high-flow season. The rationale for this is evident. Although there is an economic cost to pumping, which leads some vineyard managers to delay pumping somewhat to allow direct runoff to fill their reservoirs partially, no one who is dependent on surface water for irrigation can afford to speculate on springtime flows, or late winter flows for that matter.

Water flow in this creek is so strongly seasonal that it is not relied on for irrigation except during the winter high flow months, and the timing of withdrawals (on the recession limbs of winter storms) appears to be appropriate. The two water users with the right to pump during the spring for frost protection report that in essence they do not make use of this right; water for frost protection is pumped during the winter and stored. Springtime flow augmentation does appear to
have some potential benefit, but that the practicality of implementation and possible water temperature effects would require additional study.

After completion of the Carneros model, initial setup work began on MIKE SHE models on the other two study watersheds, Redwood and York. However, initial conversations with water users convinced NCRCD staff that the conclusion about timing of withdrawals which we drew from the Carneros model may be taken to hold for Redwood and York as well. Rather than continue with both these other models, we determined to concentrate on one, the Redwood Creek model, with particular attention to surface/groundwater interaction and to the activities of riparian diverters in the spring.

4. Redwood Creek

This project established two new gaging stations on the creek. At Napa County Flood Control and Water Conservation District graciously converted an existing station on Redwood Creek at Mt. Veeder Road (REM), by installing a new sensor better able to measure low flows, and NCRCD developed a new station on the creek at Dry Creek Road (RED). The locations of these stations are shown in Figure 2. These stations were established at locations important for adult fish passage (RED) and rearing habitat (REM).

As with Carneros Creek, a hydraulic model was constructed for the Redwood Creek watershed on the basis of the MIKE SHE modeling software developed by DHI Water & Environment, Inc. This was a finer-resolution version of the regional model developed for the Napa River watershed as a whole for the BDR. This Redwood model was constructed by NCRCD staff with the collaboration of DHI. The model domain included the entire Redwood Creek watershed down to the confluence with Browns Valley Creek to form Napa Creek, which drains to the Napa River in downtown Napa.

A. Model Input Data

Input data were derived from the same County GIS sources as the regional model and re-processed for a new model grid of 200 ft. Initially a 100 ft grid was used, as in the Carneros model, but there were difficulties with model stability at this grid resolution. The 200 ft resolution still represents a significant refinement of the regional model grid. The data source for topography was the LiDAR dataset maintained by Napa County, which was also the principal source of information on channel cross sections. After the experience of the Carneros model, it seemed most efficient to use the LiDAR-derived cross sections primarily, with additional field information at the locations of the gaging stations. Nevertheless, the lack of surveyed cross sections is a limitation of the model, since the details of cross sections could be very important for simulating low flows. As it turned out, the first set of cross sections were too long and did not interface well with the top of bank topography. A second set that were truncated at the top of bank allowed for a more appropriate representation of exchanges between the overland flow and channel flow components of the model.
For the Redwood model, rainfall information was derived from a group of publicly maintained rain stations. A total of 5 stations were used; the 5 stations were associated with areas defined by elevation-modified Thiessen Polygons. The stations are listed in Table 3. Evapotranspiration was modeled using reference evapotranspiration data from the California Irrigation Management Information System (CIMIS) record at site 77 in Oakville.

### Table 3. Redwood rainfall data

<table>
<thead>
<tr>
<th>Site Name</th>
<th>ID</th>
<th>Responsible Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt. Veeder</td>
<td>2251</td>
<td>Napa Valley Regional Rainfall and Stream Monitoring System</td>
</tr>
<tr>
<td>Redwood at Mt. Veeder</td>
<td>2253</td>
<td></td>
</tr>
<tr>
<td>Corporation Yard</td>
<td>2271</td>
<td></td>
</tr>
<tr>
<td>Alston Park</td>
<td>ALP</td>
<td>NCRCD</td>
</tr>
<tr>
<td>Castle Rock Vineyard</td>
<td>CRV</td>
<td></td>
</tr>
</tbody>
</table>

Flow data for calibration of the model were available at station RED (Redwood Creek at Dry Creek Road) for water years 2007-09. This station was established and rated for discharge under the present project as a key location for adult fish passage. The location of station RED is shown in Figure 2.

The saturated zone was modeled using essentially the information in the regional model. There was one basic saturated zone layer, with one aquifer lens carried over from the regional model, the alluvial aquifer. As in the case of the Carneros model, there were virtually no borehole data available, so that the groundwater component of the model has considerable uncertainty associated with it. Rural domestic pumping was modeled exactly as in the regional model, using the same database of well data and the same average rates obtained from the County, although in the course of model construction the wells were deepened to make sure they were able to pump most of the demand. Land use, vegetation, and soils data were derived from the same County GIS sources as the regional model and re-processed for the 200 ft model grid.

The irrigation modeling methods used in the Carneros Creek model were adopted with some modifications for Redwood Creek. There is less use of surface water for irrigation of vineyards in the Redwood Creek watershed. NCRCD investigated surface water diversions on this creek by consulting public information on water rights and interviewing vineyard managers, as we did on Carneros Creek, and also by discussing the issue with members of the Community and Technical Advisory Committee created for the project. On the basis of the latter discussions, we determined to consider the possible effects of use of water from the creek for rural residential landscaping. This topic will be further discussed in the next section.
B. Model Construction

There are distinctly fewer surface water rights on Redwood Creek than on Carneros Creek. Five major water rights were identified, but only two of these divert water from Redwood Creek itself or its major tributary Pickle Canyon Creek (the two branches included in the MIKE 11 channel flow model). These two growers farm approximately 138 acres of an estimated 1299 ac of vineyards in the model domain. NCRCD was able to interview one of the two growers, and with the information gathered from this grower and others pumping schedules were constructed. The two divert an estimated 14 ac-ft per year between them, and the effect of the timing of these two diversions was not expected to affect model results greatly.

Except for these two diverters, the bulk of the vineyards in the domain were modeled as irrigated by shallow ground water wells. In fact, conversations with local vineyard managers and technical professionals suggest that ground water is not plentiful in the Redwood Creek watershed, and it is likely that these vineyards get by on a combination of ground water, small ponds fed by surface runoff, and dry farming. It was felt that this complex variety was best represented in the model by using shallow ground water as the irrigation source.

The actual amount of irrigation appears to vary greatly, depending on availability and site factors. Most growers use somewhat less water than the 0.30 ac-ft/ac applied uniformly in the Carneros model. The vineyards in the Redwood model domain were divided into three demand groups. Groups 1 and 2 included all those with surface water rights, i.e. not only the two diverters mentioned but three others with points of diversion away from the modeled channel; Group 1 used more water than Group 2. The vineyards without surface water rights were modeled as using significantly less irrigation water, approximately half the Carneros value. Table 4 illustrates and compares these values.

<table>
<thead>
<tr>
<th>creek/demand group no.</th>
<th>Annual Irrigation, ac-ft/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carneros/all</td>
<td>0.30</td>
</tr>
<tr>
<td>Redwood/Group 1</td>
<td>0.42</td>
</tr>
<tr>
<td>Redwood/Group 2</td>
<td>0.24</td>
</tr>
<tr>
<td>Redwood/General</td>
<td>0.16</td>
</tr>
</tbody>
</table>

In the expectation that rural residential use of creek water might be significant in this watershed, NCRCD used the Napa County GIS parcel layer to identify rural residential parcels and model a projected landscaping water demand associated with these parcels. Starting with an estimated rural residential water use of 150 gal/capita/day from a recent local study (West Yost, 2005), an annual landscaping budget per parcel was calculated and applied as a steady rate throughout the spring. The use was assumed to start two weeks after the last storm of the season and was subject to the availability of water above a minimum flow threshold, at that point in the creek. Pumping stopped when the flow fell to 0.353 ft³/s (0.01 m³/s). This was done for most rural residential parcels that fronted on the creek in the model domain, with the notable exception of parcels
thought to receive City water and parcels which in spite of their GIS classification showed no sign of a residence in the aerial photos.

The model was initially set up with 100-ft grid cells, as mentioned above, but it was found that water accumulated in the overland flow component, rather than flowing downstream. Irregularities in the topography file were suspected as the cause, but efforts to raise individual cells that seemed to be “pits” did not resolve the problem. However, coarsening the model grid to 200 ft did solve the problem, while making the model run much faster as well. This type of scale-dependent behavior is common in distributed hydrologic models and the challenge for the modeler is to select a grid-resolution that accurately describes the relevant processes while considering the accuracy of the input data sets and the computational limitations of the model.

In an effort to solve the problem of excessive ponding in the overland flow component, the hydraulic conductivity in the saturated zone was altered, but this caused further problems without helping very much. Experimentation with the simpler linear reservoir method of modeling the saturated zone seemed somewhat promising, but this was abandoned as inherently incapable of addressing the scenarios of interest, since the exchange between the creek and the alluvial lens would no longer be modeled in a spatially realistic way.

As with Carneros, there were anomalies in the domestic well database which prevented some wells from functioning. In many cases, the bottoms of the well screens were higher than the ground surface. This is probably due to topographic differences between the local and regional models arising from the different grid resolutions. To make sure that these wells were able to pump most of the demand, all domestic wells were lowered substantially, as was done in Carneros. Well screens were lowered 50 m (164 ft) further into the aquifer. Agricultural wells were also lowered, for similar reasons.

C. Model Sensitivity & Calibration

The model was calibrated for the two-year period from July 2007 through June 2009, using the rainfall data and NCRCD stream gaging records for this period described above. In initial verification of the water balance, the previous year was included as well, for a more representative sampling of hydrologic years. It was found that the breakdown between surface runoff and evapotranspiration varied considerably from one year to another, depending on how wet the year was and whether the rainstorms that year were concentrated together or spread out. As with Carneros, the ensuing calibration considered both peak flow magnitudes and the overall flow record during the period from the last storm through the cessation of flow.

Overland flow and channel flow were modeled using the values from the Carneros model. Experimentation with increasing the infiltration rate showed that the Redwood model was not very sensitive to this parameter, and all values were left as in the regional model. Detention storage was implemented in the Redwood model, in contrast to Carneros, because the initial water balance appeared to be under-predicting evapotranspiration despite the inclusion of three years in the
simulation. The model proved to be quite sensitive to the exact amount of detention storage, so this was used as a final calibration parameter. The final depth of detention storage was 0.016 m (0.63 in.), distributed uniformly throughout the model domain.

Drainage was implemented in the Redwood model, and like detention storage it was distributed uniformly throughout the model domain. The drainage parameter was regarded as a way of approximating the phenomenon of interflow, which is potentially important, given the complex topography of the Redwood model; this was thought to be important because the slope of the recession limb of typical modeled storms was initially too steep. After considerable experimentation, the Redwood model implemented drainage at the very shallow level of 0.03 m (1.2 in.) below grade, using the default time constant. At this level, the volume of drainage seemed realistic and was relatively minor compared with either overland flow or baseflow to the creek.

One further parameter was important in the Redwood model, the control of the river-aquifer exchange. The modeling software permits the exchange to be controlled by the hydraulic conductivity in the aquifer (aquifer control) or by the conductivity of the bed lining (river bed control), or by a combination of the two. For Carneros, the combination was used, but for Redwood it was found that the calibration improved by setting this parameter to river bed only, and the model was quite sensitive to the selected value of the leakage coefficient which controls the exchange.

The final calibration metrics for the Redwood model are shown in Table 5. There is only one calibration point, because data were not available at the other Redwood station for the modeled period. The peak calibration considered all significant peaks, since there were no noteworthy storms after March 1 in the two years modeled. As the table shows, the peaks are dramatically higher than the observed values, a phenomenon which appeared early on in the calibration and persisted despite all efforts. However, the calibration to the springtime flow record, by far the most important component of the calibration for the project objectives, is much better; it is in fact better than the calibration achieved for the Carneros model at either calibration point. The results of the calibration are illustrated in Figure 7. Although there is a sizeable gap in the observed record, the visual fit is good, except for the unusual drops in the observed record in April. These are believed to be real and to indicate unusual springtime pumping, which will be discussed under Conclusions and Recommendations below.

Table 5. Redwood calibration results

<table>
<thead>
<tr>
<th>calibration point</th>
<th>peaks</th>
<th>overall springtime flow record</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ratio of MAE to mean of observed values</td>
<td>ratio of MAE to mean of observed values</td>
</tr>
<tr>
<td>RED</td>
<td>3.87</td>
<td>0.35</td>
</tr>
</tbody>
</table>
D. Model Applications

Since agricultural diversions from Redwood Creek are somewhat limited, the scenarios examined consider a broader range of issues. The calibrated model was used to study the following scenarios:

- **Scenario 1: Increased rural residential pumping from the creek.** This scenario assumes a distinct increase in pumping from the creek for rural residential landscaping use. The demand is increased while the minimum flow to be maintained is reduced to a slight flow of 0.1 ft³/s; the total volume diverted, about 14 ac-ft in two years, remains relatively slight compared to the total water availability in the watershed.

- **Scenario 2: Doubled alluvial well pumping.** This scenario simulates an increase in domestic well pumping in the portion of the watershed overlain by alluvium. This is done by doubling the demand in the existing wells, which have been specifically deepened to make sure they are able to pump even when the water table drops. The intent is to explore the degree to which creek flow and water movement in the alluvium are related.

- **Scenario 3: Increase in rural residential creek pumping along with increased alluvial well pumping (Scenarios 1 and 2 combined).** This scenario explores the possibility of non-linear effects from the combination of the two previous scenarios.

Scenario 1 was designed to model the effect of a significant increase in the modeled rural residential pumping from the creek, which in the calibrated model runs through the end of spring. This pumping is controlled by two model parameters, the demand and the minimum discharge required in the creek for starting and stopping the diversions. The diversion for each rural
residential parcel is located at the nearest computation point in the MIKE 11 channel model. These values are shown in Table 6, for both the calibrated model and the scenario. The scenario increases the demand by approximately a factor of ten, while reducing the flow threshold to 0.1 ft³/s. It is noteworthy that the bulk of the demand is not satisfied in either simulation, indicating that the creek flow is limiting possible diversions; in fact, the amount actually pumped in the scenario is comparable to the total demand under the base case. This scenario may be thought of as an attempt to model aggressive diversion of creek flow to this use. Figure 8 illustrates the effect of the scenario on flow at Dry Creek Road, together with that of the following Scenario 2.

Table 6. Rural residential pumping (Scenario 1)

<table>
<thead>
<tr>
<th>simulation</th>
<th>demand rate, in./day</th>
<th>Flow threshold in creek, ft³/s</th>
<th>Total volume pumped, ac-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>start</td>
<td>stop</td>
<td></td>
</tr>
<tr>
<td>base case</td>
<td>0.02</td>
<td>0.177</td>
<td>0.353</td>
</tr>
<tr>
<td>scenario 1</td>
<td>0.16</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Scenario 2, which doubles the demand for the wells located in the alluvium, has less effect on flow at Dry Creek Road than Scenario 1, even though it removes substantially more water from the ground than Scenario 1 removes from the creek. Table 7 shows the increase in well pumping under Scenario 2, and Figure 8 illustrates the relative magnitude of the two effects, as measured in the stream flow at Dry Creek Road. Although both scenarios have rather subdued effects, reducing the flow by 0.1 ft³/s or less, Scenario 1 definitely draws the flow down more than Scenario 2. It is interesting to note that Scenario 2 increases the volume of water extracted from the aquifer much more than creek pumping is increased under Scenario 1, even though the effect on creek flow is less. The effect of groundwater pumping on surface flow is indirect and limited by the relatively slow rate of groundwater movement relative to surface flow, but the model demonstrates a clear effect.

Table 7. Increased well pumping (Scenario 2)

<table>
<thead>
<tr>
<th>simulation</th>
<th>total amount pumped, ac-ft</th>
<th>domestic wells in alluvium, ac-ft</th>
<th>other domestic wells, ac-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>base case</td>
<td>166</td>
<td>55</td>
<td>111</td>
</tr>
<tr>
<td>scenario 1</td>
<td>221</td>
<td>110</td>
<td>111</td>
</tr>
</tbody>
</table>

Scenario 3, which combines the two previous scenarios into one, had the manifest effect of combining the effects of the earlier scenarios on streamflow in a linear manner, and it is not illustrated with a figure.
5. Conclusions and Recommendations

The Carneros Creek model investigated the possibility of altering the timing of surface water diversions for the benefit of fish, without harming the interests of agricultural water diverters, and it was found that, in general, the practices farmers report generally minimize pumping during the spring on this creek. As one might expect, the time of year when flows cannot be counted on for fish is also the time when farmers cannot count on being able to pump, so they have naturally concentrated on the winter high-flow season, when water is reliably available. This is a case where pursuing one’s enlightened self-interest appears to have no ill effects. By the way, the practices reported also have the effect of preserving peak flows on the creek, since pumping through the peaks means pumping silt-laden water, which is hard on equipment and shortens the useful life of storage reservoirs.

By the same logic, the additional wintertime pumping modeled in Scenario 3, in which water is diverted in the winter for the purpose of augmenting later springtime flows, appears to provide potential flow benefits during the spring without seriously reducing the ecological benefits of wintertime flows.
Interviews with vineyard managers in other watersheds suggest that springtime pumping is similarly avoided on other Napa River tributaries. However, it is possible that this may not apply to the mainstem of the Napa River, which has a more robust flow and could conceivably be relied on in the spring. This possibility was not examined under this project but could provide the subject of a useful further investigation.

Having tested this idea in the Carneros Creek situation, with its relatively intense use of surface water diversions, we chose not to pursue it further with Redwood and York Creeks. Instead, we used the relatively large Redwood Creek watershed, with its substantial number of rural residences, to model the effects of rural residential pumping and well use in the lower, alluvial portion of the creek. Modeling results of the effects of a substantial increase in these uses (which are largely unregulated) showed a small but potentially significant threat to flow in the creek, if such uses were to become more intense. Concern is perhaps most appropriate in the case of groundwater use; since the long-term impacts of groundwater use are difficult to quantify, groundwater monitoring is limited or non-existent, and the use is traditionally unregulated, it may be difficult to discern the impact of increased well use.

The results of this modeling study must be viewed in light of the limitations of the calibration for each creek. The calibrated MAE for springtime flows is one-third to one-half as great as the flows modeled, and it is quite large compared to the changes in flow observed in the scenarios. More complete input information, particularly on the groundwater system, would permit further refinement of the models, which could result in an improved understanding of the dynamics of water use, groundwater conditions and surface water flow.

The results of this modeling study permit the further conclusion that measuring these low springtime flows is important and should receive public support. Until recently, there had been no streamgaging activity on Napa River tributaries since the United States Geological Survey (USGS) discontinued their last such station several decades ago. However, the Napa County Flood Control and Water Conservation District and the NCRCD have each taken dramatic steps to remedy this. The present project is an excellent example. The ecological importance of flow in these creeks is great, and it is important to measure it so that the community knows what the available flows are and can detect any trends or potential threats to flows. This information is essential to a number of public purposes, not least the resolution of the many outstanding water right applications that exist.

Another benefit of measuring streamflow is illustrated incidentally by the observed record in Figure 7. The dramatic daily reductions in flow during April of 2008 which can be seen in the figure are believed by NCRCD staff to be real. When studied carefully, the record is thoroughly consistent with a pattern of daily withdrawals, beginning and ending abruptly, rather than being an effect of riparian vegetation drawing the creek down during a portion of the daily cycle. The latter phenomenon would much more gradual and of lesser magnitude. Measuring these flows and making the information easily available to the public is an essential step toward educating the public on the importance of maintaining springtime flows.
Acknowledgments

The modeling work reported here was substantially carried out by NCRCD staff, with support from DHI Water & Environment. When the project was resumed in late 2009 after a lengthy break in state funding, the modeling work was completed by consulting hydrologist Robert Zlomke with assistance from O’Connor Environmental, Inc. DHI graciously reviewed the final report.

NCRCD is grateful to the many agricultural water diverters on Carneros and Redwood Creeks who contributed information on their diversion and irrigation practices, and to the Napa County Conservation, Development and Planning Department for assistance in transferring information from the regional model to the project and with other data needs. We also acknowledge the provision of rain data at no charge by the Agri-Link network for the Carneros model.

Principal funding for the project came from the CALFED Bay-Delta Watershed Program, with matching funding from a variety of local sources.

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