Vegetation Modeling of the Trinity River between Lewiston Dam and the North Fork Trinity River

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Abstract

SRH-1DV, developed by the Sedimentation and River Hydraulics Group of Bureau of Reclamation, was selected to simulate the vegetation establishment, growth, and desiccation in a 40-mile reach of the Trinity River between Lewiston Dam and the North Fork Trinity River. Upon the completions of the Trinity and Lewiston Dams in the early 1960s, the dams stored and transferred water resources of the Trinity to the Sacramento River and the Central Valley. These dams regulated the flows and reduced the flow peaks. Historic flows ranging from 100 to 100,000 cfs were regulated to nearly constant flows between 100 to 300 cfs. The elimination of the high flow regime reduced the channel dynamics of the river and changed the river into a narrow, single channel in most areas, and thus reduced salmonid habitat. A combination of active revegetation (plantings) and natural regeneration and recruitment processes are applied to address the vegetative restoration component of Trinity River Restoration Program (TRRP). Application of our numerical model aids in understanding the river processes and supports predictions of future physical conditions.

In this application of SRH-1DV, four basic vegetation communities are simulated: cottonwood, white alder, narrowleaf willow, and shiny willow. The numerical model covers 10 years from 2001 to 2011. Vegetation map 2001 is used to provide initial vegetation conditions regarding vegetation density and age. Vegetation establishment, growth, and desiccation are modeled and results are compared with the 2011 vegetation map. The goal of this study is for us to understand how well SRH-1DV can be used to replicate vegetation growth and mortality on the Trinity River, demonstrate the potential and limitations of the model on Trinity River vegetation, and identify future study directions.

Introduction

The Bureau of Reclamation's (BOR) Trinity River Restoration Program (TRRP) is actively rehabilitating the Trinity River between Lewiston Dam and the North Fork Trinity River. Upon the completions of the Trinity and Lewiston Dams in the early 1960s, the dams stored and transferred water resources of the Trinity to the Sacramento River and the Central Valley. Trinity Dam was completed in 1962. Lewiston Dam, about 8 miles downstream from Trinity Dam, was completed in 1963.

Up to 90% of the annual water yield of the Trinity was diverted for agricultural and urban uses (Bair, 2001). These dams regulated the flows and reduced the flow peaks. Historic flows ranging from 100 to 100,000 cfs were regulated to nearly constant flows between 100 to 300 cfs.

The elimination of the high flow regime reduced the channel dynamics of the river and changed the river into a single channel in most areas, and thus reduced salmonid habitat.

A combination of active revegetation (plantings) and natural regeneration and recruitment processes are applied to address the vegetative restoration component of TRRP. Active planting is accomplished by planting and initially irrigating willow and cottonwood species in the floodplains and river banks. Natural regeneration and recruitment processes are being accomplished by restoring some of the high flow regime and by construction of side channels and floodplains. The long-term goal is to restrict vegetation encroachment along the low water edge while encouraging establishment on floodplains.

SRH-1DV, developed by the Sedimentation and River Hydraulics Group of Bureau of Reclamation, was selected to simulate the vegetation establishment, growth, and desiccation in a 40-mile reach of the Trinity River between Lewiston Dam and the North Fork Trinity River. The vegetation model uses the 2001 vegetation map, developed by McBain and Trush and USDA Forest Service Redwood Science Laboratory (RSL) (Mcbain and RSL, 2004). The vegetation map was based on low altitude ortho-rectified air photos (1:1,200 scale) from Lewiston Dam (RM 112.0) to the North Fork Trinity River (RM 72.4), taken in November 2001, with a Lewiston Dam release of 300 cfs. The vegetation map was then verified with field surveys during July and October 2003. The mapping boundary was defined as 820 ft (250m) from the channel centerline and 82 ft (25m) vertically above the water surface, whichever occurred first. Forty-one different cover types were mapped and field verified along the Trinity River mainstem. Most cover types were synonymous with a plant stand. However, four non-plant dominated cover types were also mapped: (1) human disturbance, (2) open ground, (3) open water, and (4) roads. The remaining 37 cover types were all dominated by a single plant species or co-dominated by two or more plant species.

In this application of SRH-1DV, four basic vegetation communities are simulated, which include cottonwood, white alder, narrowleaf willow, and shiny willow. Vegetation establishment, growth, and desiccation are modeled, and results are compared with the 2011 vegetation map (Hoopa Valley Tribe and McBain Associates, 2015). The goal of this study is to understand how well SRH-1DV can be used to replicate vegetation growth and mortality on the Trinity River and demonstrate the potential and limitations of the model on Trinity River vegetation.

Model Description

SRH-1DV is an extension of the Sedimentation and River Hydraulics - One Dimensional (SRH-1D), a 1D flow and sediment transport model developed by the Technical Service Center (TSC) (Huang and Greimann, 2007). The model is capable of simulating steady and unsteady flows, internal boundary conditions, cohesive and non-cohesive sediment transport, and lateral inflows in natural rivers and constructed canals with or without mobile boundaries. SRH-1DV was developed to include ground water and vegetation simulation (Fotherby, 2013; Greimann et al., 2011).

Groundwater Module

Groundwater elevation is a critical factor in the survival of riparian vegetation and is predicted in the model from the computed water surface in the river. The ground water module within

SRH-1DV is a cross-section based saturated flow model. Ground water levels are a function of the river water elevation and a soil permeability coefficient. The module solves for the ground water levels, and assumes no ground water interaction between cross sections. Therefore, the ground water solutions obtained from SRH-1DV will only be applicable near the river, i.e., generally within the alluvial soils of the floodplain.

Vegetation Establishment Module

The Establishment Module simulates germination due to air dispersal assuming an unlimited supply of seed. If air dispersal is being simulated, a plant is assumed to germinate if there is available space, available seeds and moist soil. Established plants can also expand to adjacent points through lateral spread of roots. Narrow leaf willow and similar plants are able to expand through lateral growth of roots. These plants can colonize closely spaced adjacent points in the cross section or even closely spaced adjacent cross sections.

Vegetation Growth Module

The Growth Module calculates vertical growth of the root (depth), stalk (height), and canopy (width). User-specified growth rates for the roots, stalks, and canopy are based upon the month and age of the plant; that is, a growth rate can be assigned for each month of the first year, and then different growth rates can be assigned for each subsequent year of plant life. Root growth is computed at the specified rates until reaching a user-specified depth with respect to the ground water table. Stalk growth and canopy width are also computed and tracked in the Growth Module until the plant reaches an assigned maximum height or width for the vegetation type.

Vegetation Mortality Module

The Mortality Module calculates whether the plant survives each time step. There are multiple ways a plant may die in this study, and thus be removed from the module:

- Desiccation, if a plant experiences too much stress due to lack of water;
- Scour, if the local flow velocity at the plant becomes larger than a user-specified value;
- Inundation, if flows exceed the root crown by an assigned depth and flow duration;
- Competition, where assigned rules define the dominant plants; and
- Shading, when a susceptible plant is under the canopy of another plant.

Flow Model Input

In this study, only the flow and vegetation parts of SRH-1DV are used.

Hydrology

Five stream gages in the Trinity River and three gages in the tributaries are operated and maintained by the U.S. Geological Survey (USGS) in the study reach. The numerical model uses flow at the Trinity R A Lewiston CA Gage (USGS 11525500) as the upstream boundary conditions, and adjusts the flow in the river according to the downstream gages in the river or tributaries. Flows from the tributaries are simulated as point sources. The difference between a downstream gage and the combination of upstream gage and tributaries between these two gages is treated either as point source or non-point source.

Cross Section Geometry

Cross section geometry was obtained from a separate study performed by the Northern Region Office of the California Department of Water Resources (CDWR, 2014). CDWR performed the hydraulic computations from Lewiston Dam to just downstream of the North Fork Trinity River (River Mile 112.16 to 72.23). The geometry data were based on a 2009 terrain developed from a compilation of ground control, bathymetry, and LiDAR (Light Detection and Ranging) data acquired during the month of April 2009. The terrain was converted to a Triangulated Irregular Network (TIN) and then interpolated into SRH-1DV cross section geometry.

Other Parameters

Downstream boundary conditions were determined based on a rating curve of water surface elevation and discharge at the downstream most cross section (RM 72.23). Channel and overbank roughness values (Manning's n values) were kept the same based on previous HEC-RAS numerical simulations (CDWR, 2014). The overbank roughness was set as 0.08 and the channel roughness was set as 0.045. In the groundwater module, the hydraulic conductivity of the soil was set as 100,000 ft/day and the capillary fringe height is set as 0.8 ft. The time steps were set as one hour for river flow and ground water simulations and 1 day for vegetation simulation.

Vegetation Input

Vegetation data required as input to the model include germination, growth, and mortality parameters for each modeled vegetation type along with an initial vegetation conditions map. This study used the 2001 vegetation inventory as the initial conditions map and initially adopted vegetation parameters from other research. The model was run for approximately 10 years, and the vegetation parameters were calibrated such that final vegetation map matched the 2011 vegetation inventory as closely as possible.

Vegetation Alliances

Four vegetation types or alliances were selected to represent species or communities of interest in the Trinity River (Table 1). Black cottonwood (*Populus balsamifera ssp. Trichocarpa*) and Fremont cottonwood (*Populus fremontii*) are combined into a single type. Two vegetation types are used to represent willows. One is used for shrub-type willows, including narrowleaf willow (*Salix exigua*) and dusky willow (*Salix melanopsis*), and another is used for large shrub or small tree-type willows, including arroy willow (*Salix lasiolepis*), shiny willow (*Salix lucida* ssp. *Lasiandra*), and red willow (*Salix laevigata*). White alder (*Alnus rhombifolia*) is also simulated in the model. One alliance, referred to as the Other Alliance was used to represent all the other vegetation, where no vegetation establishment, growth, and desiccation are modeled. Some are upland species that are not influenced by the flows in the river channel. Some of the species in the Others category are riparian plants which can be simulated in future studies. The last alliance, referred to as the No Grow alliance was used to represent roads, agriculture area, and other distributed areas, where none of the other alliances are permitted to grow. Agricultural lands are designated as a no-grow surface to distinguish between plant growth on cultivated and uncultivated lands.

Table 1. Vegetation alliances modeled in SRH-1DV.

Modeled Vegetation Alliance	Latin Name	Abbreviation
Black Cottonwood Fremont Cottonwood	*Populus balsamifera* ssp. *Trichocarpa* *Populus fremontii*	BKCW
White Alder	*Alnus rhombifolia*	WHAD
Narrowleaf Willow Dusky Willow	*Salix exigua* *Salix melanopsis*	NLWL
Arroyo Willow Shiny Willow Red Willow	*Salix lasiolepis* *Salix lucida* ssp. *Lasiandra* *Salix laevigata*	OTWL
Others	NA	OTER
No Grow (ag and roads)	NA	NOGR

Germination, Growth and Mortality Parameters

The model requires germination, growth, and mortality parameters for each vegetation alliance being simulated. Information including root growth rates, stem growth rates, canopy spread rates, capillary fringe height, germination seasons, germination time, longevity of seeds, basal sprouting, and days for desiccation mortality were based primarily on values from Mahoney and Rood (1998), McBride and Strahan (1983), Shafroth et al. (1998), and Stella et al. (2006). Values were also selected from USDA plant guide information and from previous flow-sediment-vegetation modeling by Reclamation's Sedimentation and River Hydraulics Group (Fotherby, 2013; Gordon, 2011; Greimann et al., 2011; Greimann et al., 2007; and Murphy et al., 2006) and calibrated in this study. When no other information was available regarding a particular species, values were assigned based on similar vegetation types or general field observations of physical attributes. No previous germination, growth, and mortality parameters are available for white alder, and therefore values were estimated from USDA plant guide information and Bair (2001).

Initial Vegetation Conditions

SRH-1DV allows the user to input initial vegetation conditions for each point in each cross section. Identification of the vegetation present at the beginning of the simulation for each point is accomplished through a polygon shapefile containing areas assigned with a specific vegetation type.

The vegetation model uses the 2001 vegetation inventory map, developed by Mcbain And Trush and USDA Forest Service Redwood Sciences Laboratory (Mcbain and RSL, 2004). The vegetation map was based on low altitude ortho-rectified air photos (1:1,200 scale) from Lewiston Dam (RM 112.0) to the North Fork Trinity River (RM 72.4), taken in November 2001, with a Lewiston Dam release of 300 cfs. The vegetation map was then verified with field surveys during July and October 2003. The mapping boundary was defined as 820 ft (250m) from the channel centerline and 82 ft (25m) vertically above the water surface, whichever occurred first.

Five vegetation types or alliances were selected to represent species or communities of interest in this Trinity River study: cottonwood (BKCW); white alder (WHAD); narrowleaf willow (NLWL) including narrowleaf willow and dusky willow; other willows (OTWL) including arroyo willow, shiny willow, and red willow; and all other vegetation. No Grow alliance was used to represent roads, agriculture area, and other distributed areas.

Each mapped community of vegetation was assigned an age and density for at least one of the six vegetation alliances including No Grow. The age and density for the initial conditions were estimated from descriptions provided in the vegetation inventory and mapping. Vegetation density represents the percentage of the area occupied by the vegetation type. In SRH-1D, a vegetation type only exists in a fraction of stations in a cross section. For example, if cottonwood has a density of 0.8 (80%) in polygons with vegetation code BC and 10 points of cross section stations are located in polygons BC, 8 points will be assigned as cottonwood, and 2 points will be assigned as no vegetation.

Results

Numerical simulation was performed from November 15 2001 through April 15 2011 with historical flow rates as discussed in Section 2.1. The extent of the 2001 and 2011 vegetation inventory maps is different. The 2001 vegetation inventory map covers a larger area than the 2011 map, and some areas in the 2011 map are not covered by 2001 map. For comparison, both maps were clipped in GIS to keep the same overlapped area, and the numerical model was calibrated only in the remaining area.

Vegetation Area with Density Considered

SRH-1DV simulates vegetation density by initially assigning vegetation on a percentage of station points in a cross section. After the simulation, all station points in a cross section were counted to estimate the area changes in each vegetation polygon.

Initial and final vegetation areas for each vegetation alliance are summarized in Table 2. The mortality areas for each vegetation alliance were also listed. The model represented both the correct magnitude and direction of change for each simulated vegetation alliance.

Table 2. Initial and final vegetation areas and removed vegetation areas due to different mortality mechanism.

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="4">Vegetation Area (Acres)</th></tr>
<tr><th>BKCW</th><th>WHAD</th><th>NLWL</th><th>OTWL</th></tr>
<tr><td rowspan="7">Living</td><td colspan="2">2001 Mapping</td><td>36.8</td><td>246.6</td><td>254.1</td><td>129.3</td></tr>
<tr><td colspan="2">2011 Mapping</td><td>31.6</td><td>177.0</td><td>262.4</td><td>154.5</td></tr>
<tr><td rowspan="3">2011 Simulated</td><td>Total</td><td>30.0</td><td>185.4</td><td>259.3</td><td>153.9</td></tr>
<tr><td>Old</td><td>30.0</td><td>185.4</td><td>136.2</td><td>110.6</td></tr>
<tr><td>New Growth</td><td>0</td><td>0</td><td>123.1</td><td>43.3</td></tr>
<tr><td colspan="2">Field Change</td><td>-14%</td><td>-28%</td><td>3%</td><td>19%</td></tr>
<tr><td colspan="2">Modeled Change</td><td>-19%</td><td>-25%</td><td>2%</td><td>19%</td></tr>
<tr><td></td><td colspan="2">Competition</td><td>0</td><td>0</td><td>12.6</td><td>1.6</td></tr>
</table>

Mortality cause	Desiccation	1.9	39.3	68.6	6.9
	Drowning	0	20.9	3.1	4.2
	Scour	5.0	1.0	33.6	6.0

Vegetation Calibrated with Visual Inspection

2011 aerial photographs were used to visually check the vegetation modelling results regarding vegetation establishment, survival, and different types of mortality. In areas where 2011 aerial photographs were not available, 2010 and 2014 aerial photos were used. Currently, SRH-1DV simulates vegetation mortalities due to competition, inundation, desiccation, and scour. Inundation mortality was predicted to occur most inside the channel or in the side channel, where water covers the vegetation even during a low flow stage. Desiccation mortality was predicted mostly on highlands where the vegetation roots could not reach the ground water. Predictions of scour mortality were most frequently in shallow channel areas, where the water velocity exceeds the critical velocity.

Figure 1 and Figure 2 show the initial and simulated final vegetation status for cottonwood at Station 94.35, on aerial photos 2001 and 2010, respectively. Because the 2011 aerial photograph was unavailable at this site, the 2010 aerial photo was used. At this station cottonwoods did not survive due to scour on the left side of the channel near the left bank (right bottom of the channel), and did survive on the right floodplain. In the figures, larger size dot represents initial condition and smaller final condition. The color of a dot represents the vegetation status (green: alive; white: no vegetation; brown: mortality due to shade and competition; black: mortality due to drown; red: mortality due to desiccation; and purple: mortality due to scour).

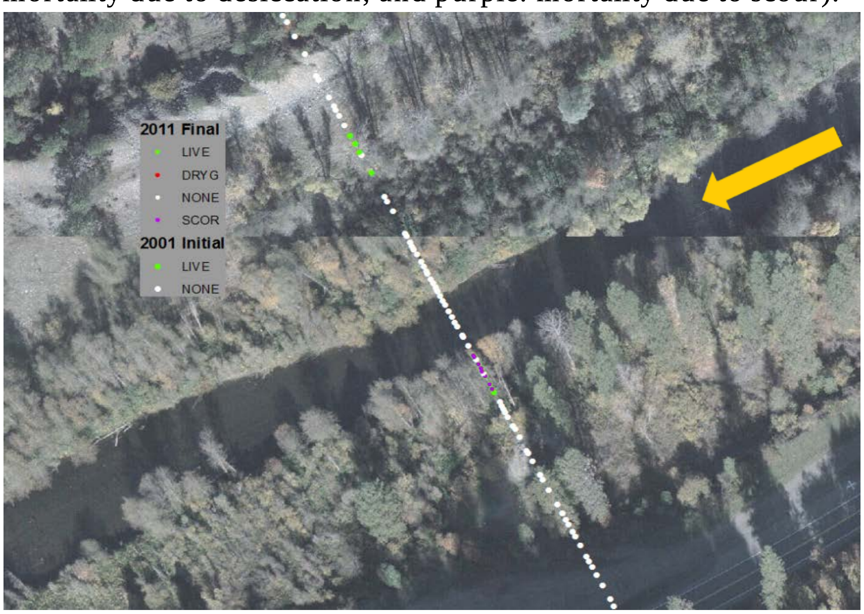

Figure 1. Initial and final cottonwood existence and mortality illustrated at Station 94.35 on 2001 aerial photo.

Figure 2. Initial and final cottonwood existence and mortality illustrated at Station 94.35 on 2010 aerial.

Figure 3 through Figure 5 show the initial and simulated final status of shrub-type willows (NLWL) at Station 92.25. The primary cause of mortality for the shrub-type willows was desiccation and drowning. The numerical model shows that shrub-type willows (narrowleaf and dusky willows) were killed by scour at two locations; the one on the right side of the channel (at the center of the figure) is not supported by the 2010 aerial photo, but is clear in the 2014 aerial photo, and the one near the left bank (left side of the figure) is not supported by either the 2010 or 2014 aerial photos. New narrowleaf willows were established on right floodplain.

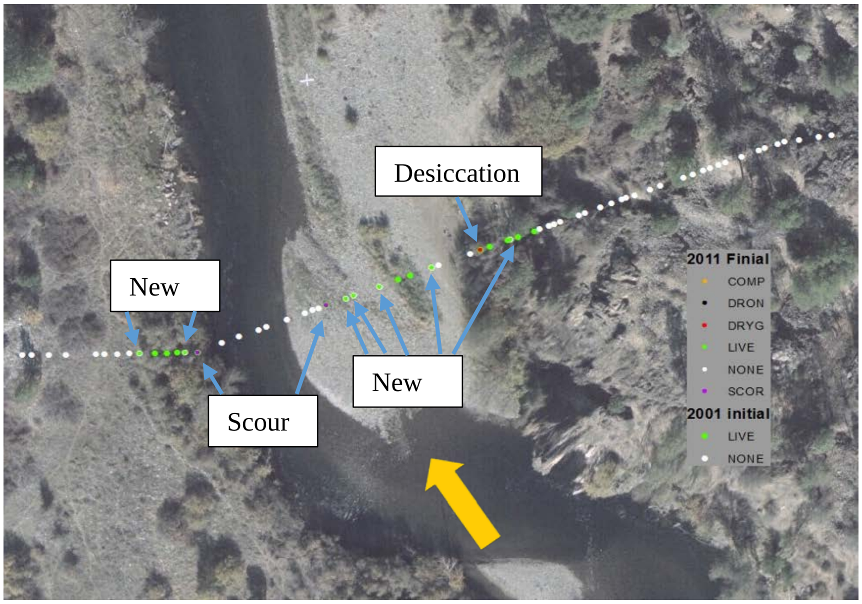

Figure 3. Initial and final narrowleaf willow existence and mortality illustrated at Station 92.25 on 2001 aerial photo.

Figure 4. Initial and final narrowleaf willow existence and mortality illustrated at Station 92.25 on 2010 aerial photo.

Figure 5. Initial and final narrowleaf willow existence and mortality illustrated at Station 92.25 on 2014 aerial photo.

Summary

SRH-1DV is used to simulate the vegetation germination, growth, and desiccation in a 40-mile reach of the Trinity River between Lewiston Dam and the North Fork Trinity River. Four vegetation types or alliances were selected to represent species or communities in this study, which include cottonwood, white alder, shrub-type willow, and large brush and tree-type willows. Two additional types were used in the model, one for all the other riparian vegetation alliances and one to represent roads, agriculture area, and other distributed areas. The numerical model spanned a 10-year period from November 2001 to April 2011. A vegetation inventory from 2001 was used to provide initial vegetation conditions regarding vegetation density and age. A vegetation inventory from 2011 was used to calibrate the model regarding each vegetation parameter.

The numerical model roughly reproduced the survival rate of cottonwood, white alder, shrub-type willow, and other large brush and tree willows based on the predicted area covered by each vegetation types. A qualitative comparison of model results and field conditions was used to examine the existence and mortality of each vegetation type.

While it may not be realistic to expect a 1D numerical model to quantitatively predict the specific locations of vegetation survival, mortality, and establishment, the calibrated numerical model can be used to compare the general vegetation response under different river restoration flow and management alternatives.

Acknowledgments

The authors would like to acknowledge James Lee of the Hoopa Valley Tribe and Trinity River Restoration Program and John Bair of McBain Associates who lead the field trip and provided information and discussions. Comments from James Lee, John Bair, and Todd Buxton are appreciated. The initial vegetation parameters are from Gordon (2011) and Greimann et al. (2011).

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