RECLAMATION
Managing Water in the West

Effects of Climate Change and Reservoir Operations on Riparian Vegetation

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Executive Summary

This report documents the Science and Technology (S&T) project titled "Effects of Climate Change and Reservoir Operations on Riparian Vegetation" carried out during fiscal year 2014 through 2016 (a 3-year study). The focus of the research is to develop numerical models of riparian vegetation that can be used to assess the effect of climate change and reservoir operations on riparian vegetation.

Collaborative partners on the research include:

- Blair Greimann, Ph.D., Hydraulic Engineer, Technical Service Center, Bureau of Reclamation, Denver, Colorado
- David Merritt, Ph.D., Riparian plant ecologist, US Forest Service Research & Development, Fort Collins, CO
- Dan Dombroski, Ph.D., Hydraulic Engineer, Technical Service Center, Bureau of Reclamation, Denver, Colorado
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Key accomplishments of the project are:

1. Compared Riparian Vegetation simulation module in SRH-1DV to observed riparian vegetation changes on the Sacramento, San Joaquin and Trinity Rivers
2. Developed methodology to model the effects of vegetation on sediment transport.
3. Funded David Merritt of the US Forest Service to apply guild model to San Joaquin River as a demonstration of the methodology to assess effects of project operations on vegetation simulation. The guild model

Task 3 is still in progress as the funding for this task was allocated to US Forest Service in June of 2016 and their work will not be complete until late in 2017.

The reports produced as part of this research include:

Greimann, B.P. (2016). "Modeling Riparian Vegetation on Sacramento River with SRH-1DV." *RiverFlow2016*, St Louis, MO, George Constantinescu, Marcelo Garcia, Dan Hanes (Eds.).

Reclamation (2015). *2015 SRH-1DV Vegetation Modeling of the San Joaquin River from Hwy 99 to Chowchilla Bypass*, Technical Report No. SRH-2015-40, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.

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Reclamation (2016b). *Modeling Effects of Vegetation on Sediment Transport Computations*, Technical Report No. SRH-2016-31, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.

Background on the vegetation simulation module can be found in:

Reclamation (2011) *Calibration of Numerical Models for the Simulation of Sediment Transport, River Migration, and Vegetation Growth on the Sacramento River, California, NODOS Investigation Report*, Technical Report No. SRH-2009-27, Technical Service Center, Bureau of Reclamation, Denver, CO.

Reclamation (2012). *Vegetation Modeling with SRH-1DV, Predicting the Interactions between Flow, Sediment, and Riparian Vegetation*, Technical Report SRH-2012-12, Bureau of Reclamation, Technical Service Center, Denver, CO.

Contents

1. Background

The Bureau of Reclamation (Reclamation) is responsible for implementing several large scale river restoration projects throughout the western United States (Reclamation, 2011). These include the San Joaquin River Restoration Program, Central Valley Project Improvement Act, Trinity River Restoration Program, and the Middle Rio Grande Endangered Species Collaborative Program. In all of these basins, a healthy riparian corridor is critical to habitat sustainability. In all of these restoration programs, there are large reservoirs that regulate flows and there is the ability to affect the recruitment, growth, and survival of riparian species. Climate change will potentially create additional stress on native species within the riparian corridor and therefore put additional stress on the habitat. The need for a quantitative understanding of riparian processes is summarized in Perry et al. (2012): “Together, climate change and climate-driven changes in streamflow are likely to reduce abundance of dominant, native, early-successional tree species, favor herbaceous species and both drought-tolerant and late-successional woody species (including many introduced species), reduce habitat quality for many riparian animals, and slow litter decomposition and nutrient cycling. Climate-driven changes in human water demand and associated water management may intensify these effects. On some regulated rivers, however, reservoir releases could be managed to protect riparian ecosystem.”

There are few quantitative models that link the hydrology and hydraulic conditions in the river directly to the recruitment and survival of riparian species. Some examples of riparian models are Benjankar et al (2011) and García-Arias et al (2012) where vegetation models are linked to complex hydraulic models. However, these models were developed for specific river systems and a more general purpose model is needed that is focused on the management questions faced in Reclamations. Specifically, we would like to develop a tool to answer questions such as:

1. What is the potential range of effects of future climate changes on the establishment and sustainability of riparian forests in managed river systems?
2. What set of reservoir operations can be used to encourage successful native vegetation recruitment and survival under projected climate change scenarios?
3. Can reservoir operations be used to control other potential indirect effects such as invasive species?

The survival of riparian vegetation within managed river systems is a growing challenge due to the increasing priority of maintaining or restoring ecosystem function while balancing the need for water supply and flood protection. Establishment, growth, and decay of riparian vegetation is heavily influenced by local hydraulics; conversely, characteristics of in-channel and floodplain vegetation effect hydraulics and sediment transport from the patch to reach scale. Despite a wealth of prior research concerning the mechanics of flow-vegetation interactions, the need for operation-level tools for making quantitative predictions remains.

This project has accomplished three major tasks:

1. Compared Riparian Vegetation simulation module in SRH-1DV to observed riparian vegetation changes on the Sacramento, San Joaquin and Trinity Rivers
2. Developed methodology to model the effects of vegetation on sediment transport.
3. Funded David Merritt of the US Forest Service to apply guild model to San Joaquin River as a demonstration of the methodology to assess effects of project operations on vegetation simulation.

Task 3 is still in progress as the funding for this task was allocated to US Forest Service in June of 2016 and their work will not be complete until later in 2017. The intention of this task is to develop an alternative modeling framework that is built upon a probabilistic structure rather than a deterministic once. In additional, the guild model approach groups species into functional categories rather than simulating each individual species. The outcome of this task will also be a comparison between the two approaches. It is likely that there will be advantages and disadvantages of each approach and that depending upon the specific questions being asked of the model, one approach may be more applicable than the other. A general description of the modeling approach can be found in Merritt et al. (2009).

In the main body of this report, the first two tasks carried out at Reclamation are summarized and the detailed references are included as attachments.

2. SRH-1DV comparison to observed changes

The Sedimentation and River Hydraulics Group has developed a dynamic tool called SRH-1DV to quantify ecologic change in response to geomorphic change, by simulating vegetation adjustments to altered flow regimes, sediment regimes, groundwater, and terrain (Reclamation, 2011; Reclamation, 2012). It is built upon the SRH-1D model, which is a mobile bed sediment transport model (Huang and Greimann, 2010). Investigating the impacts from the rapid spread of an invading riparian species is also possible with this platform. Representation of vegetation is based on the vegetation continuum that ascribes plant species distribution to individualized species response to the environment. A unique set of responses and coping mechanisms define the zone of coverage that is specific to each vegetation type, and zones may partially overlap and be shared between species. Terrain, flow, sediment, and groundwater conditions in a daily simulation can be linked to plant germination, growth, and mortality including plant removal from desiccation, inundation, erosion, shade, competition, burial, and senescence.

This tool offers three advantages to a vegetation assessment: dynamic representation of physical conditions; the means of accurately representing distinct plant species; and a process-based assessment of plant survival. Site specific factors are less likely to be muted or lost in this alternative to elevation-based studies, plant community simulations, or simulations of historical progressions. Detailed predictive-modeling can aid resource managers in assessing

The vegetation module tracks the growth of plants with respect to groundwater and surface flow at every point in the model, and with respect to terrain and terrain changes resulting from sediment transport. The vegetation life-cycle is idealized as three phases: 1. establishment, 2. growth, and 3. mortality. Similar to the vegetation observed in the field, the vegetation simulated in SRH-1DV will colonize sites and compete for survival using adaptive techniques and growth rates specific to each type of plant, and in response to daily conditions at every point. Mechanisms of plant growth can be switched on or off and adjusted through the vegetation input file to match the characteristics of each vegetation type. These descriptors differentiate the plants and improve the simulation of plant life.

Three different applications of SRH-1DV are documented in separate reports attached to this one. The model applications are on the Sacramento, San Joaquin, and Trinity Rivers. All three rivers have large Reclamation reservoirs on them that to some extent regulate the flow in the river and all three rivers have large restoration programs: Central Valley Project Improvement Act, San Joaquin River Restoration Program, and the Trinity River Restoration Program. Riparian vegetation plays a critical role in all three restoration programs because it is critical to the sustainability of habitat along the river corridors. The applications of the model were performed at these three rivers because there was large scale riparian vegetation mapping separated by approximately a decade that could be used to evaluate model performance.

2.1 Sacramento River

SRH-1DV application to Sacramento is documented in Greimann (2016) given in Attachment A. Detailed survival information on cottonwood survival was collected point bars in the Sacramento River downstream of Red Bluff at River Mile (RM) 192.5 and 183 by California Department of Water Resources in 2005 and 2006. The site at RM 192.5 was a gravelly soil while the site at RM 183 was sandy, and provided a test of the desiccation function for both gravelly and sandy soils. The model was able to simulate the time of establishment, whether the cottonwoods survived and the elevation of recruitment. Model results were in agreement with observations that indicated that the seedlings in the sandy soil survived until the fall, but that no cottonwoods survived in the gravelly soil.

A second calibration of the SRH-1DV vegetation module was based on vegetation changes between 1999 and 2007 GIS vegetation mapping for RM 144 to RM 245 for a total of 100 miles. 1997 mapping was used for the simulated input conditions. The comparison of simulated results of vegetation coverage and mapped results was a verification of Fremont cottonwood parameters and a calibration of parameters for mixed forest, Gooding's black willow, and sandbar willow. Model results are based on sandy soils. One potential problem with the application of riparian vegetation models is that soil texture is a primary factor in the survivability of riparian species and it is difficult to represent the heterogeneous nature of soil conditions near the river. In this study, it was found that reasonable results could be obtained by assuming all the soil was homogenous and could be represented by the sandy soil.

Most cottonwood parameters in the SRH-1DV model were previously calibrated to field data and verified here but not adjusted. The simulated area of mixed forest was larger than that measured from the mapping. When two woody vegetation types are combined as forest, there is a one percent difference between mapped ratios and model simulated ratios. Mapped riparian areas include riparian scrub and riparian vegetation and simulated riparian areas are Gooding's black willow and sandbar willow. Combined riparian scrub and riparian vegetation (mapping) have a 40-percent increase, similar to riparian model results for Gooding's black willow and sandbar willow that predict a 35-percent increase.

2.2 San Joaquin River

The application of SRH-1DV to the San Joaquin River is given in Reclamation (2015) in Attachment B. SRH-1DV is used to simulate the vegetation germination, growth, and desiccation in Reaches 1B and 2A of the San Joaquin River, CA. Six vegetation types or alliances were selected to represent species or communities in this study, which include Fremont cottonwood, Goodings black willow, sandbar willow, generic grass, red sespania, and arundo. The numerical model covers 12 years from Oct. 1 2000 to Sept. 31 2012. Vegetation map 2000 was used to provide initial vegetation conditions regarding vegetation density and age. The vegetation model uses the 2000 vegetation map, developed by Environmental Services Section of the California Department of Water Resources' San Joaquin District. Vegetation was classified using a modified Holland system (Holland, 1986) and eleven basic vegetation communities were found and used along the San Joaquin. These include cottonwood, riparian forest, herbaceous (=grassland), mixed riparian forest, willow riparian forest, riparian oak forest, riparian scrub, river wash, wetland, willow scrub, exotic tree (usually *Eucalyptus* or tree of heaven [*Ailanthus altissima*]), and Arundo (*Arundo donax* or giant reed).

The vegetation map from 2012 was used to calibrate the model regarding each vegetation parameter. Due to the different methods to classify the vegetation maps in 2000 and 2012, the vegetation map 2012 was only used to visually calibrate the numerical model. The numerical model provides vegetation coverage in terms of initial and final vegetation areas for each vegetation alliance, removed vegetation areas due to different mortality mechanisms. Vegetation maps in two time stages with the same classification methods are desired to better calibrate the numerical model.

Even though it was not possible to compare the model against observed changes to vegetation area, the model proved useful in quantify potential mortality mechanism such as desiccation, drowning, and scour. It may also be used to quantify the difference between various reservoir operations relating to the recruitment of riparian vegetation.

2.3 Trinity River

The application of SRH-1DV to the Trinity River is given in Reclamation (2016a) in Attachment C. 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. Due to model run time limitations, the calibration of the numerical model uses a total of 201 cross sections out of the 785 total available HEC-RAS cross sections. Four vegetation types or alliances were selected to represent species or communities in this study, which include cottonwood, white alder, shrub-type willow (NLWL), and large brush and tree-type willows (OTWL). 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, shrubtype 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. Several example locations were presented at representative river cross sections.

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.

2.4 Summary of Model Applications

The SRH-1DV model was valuable in understanding various mortality mechanisms and in predicting general trends in riparian vegetation. Calibration of the model can be difficult, however, because it is difficult to obtain two comprehensive datasets where the vegetation was classified consistently. It is much easier to compare the model against point bar scale data where detailed observation was performed over time consistently.

Numerical modeling can help to identify distinctions between flow management alternatives by tracking the complex response of vegetation to geomorphic change. SRH-1DV applications also offer secondary benefits by enhancing our understanding of complex processes and response. Reclamation can include SRH-1DV simulations in project studies to assist managers develop well-considered flow, sediment, and land actions for optimal environmental benefits. Plans for the future include improvements and continued verification of plant growth mechanisms and parameter selection for SRH-1DV, and development of a complementing two-dimensional (2D) vegetation model for more detailed assessment of local conditions.

3. Literature Review and Conceptual Model of Effects of Vegetation on Sediment Transport

The literature review of the effects of vegetation on sediment transport is documented in Reclamation (2016b) given in Attachment D.

Current sediment transport models such as SRH-1D, SRH-2D, HEC-RAS, etc... do not consider the effect of vegetation on sediment transport. This can lead to non-physical behavior in floodplain because the flow energy extracted by the vegetation is assumed to transport sediment. Often, this can lead to a gross overestimation of transport of sediment through floodplains.

A coupled two-dimensional vegetation and hydraulic model has been developed at the Bureau of Reclamation. The model is based upon the SRH-2D computational software package, which contains a two-dimensional flow and mobile bed sediment transport model. The new SRH-2D package incorporates a coupled module that computes spatially-distributed, dynamic roughness based on measured vegetation characteristics. Although the module enhances the ability to predict stage relations as a function of vegetated flow conditions, it lacks the robustness in modeled physical processes required to systematically predict effects on sediment transport. Explicit treatment of the vegetative drag and partitioning of stresses that induce substrate mobilization has been shown to provide an effective means of modeling the physical processes involved. A brief review of literature and theory describing vegetation-sediment interactions is provided along with the current development trajectory for implementing algorithms within the SRH-2D modeling framework.

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Reclamation (2016b). *Modeling Effects of Vegetation on Sediment Transport Computations*, Technical Report No. SRH-2016-31, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.

Attachment A.

Greimann, B.P. (2016). "Modeling Riparian Vegetation on Sacramento River with SRH-1DV." RiverFlow2016, St Louis, MO, Edited by George Constantinescu, Marcelo Garcia, Dan Hanes (Eds.).

Attachment B.

Reclamation (2015). *2015 SRH-1DV Vegetation Modeling of the San Joaquin River from Hwy 99 to Chowchilla Bypass*, Technical Report No. SRH-2015-40, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.

Attachment C.

Reclamation (2016). *SRH-1DV Vegetation Modeling of the Trinity River between Lewiston Dam and the North Fork Trinity River*, Technical Report No. SRH-2016-12, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.

Attachment D.

Reclamation (2016b). *Modeling Effects of Vegetation on Sediment Transport Computations*, Technical Report No. SRH-2016-31, Sedimentation and River Hydraulics Group, Technical Service Center, Bureau of Reclamation, Denver, CO.