VEGETATION CALIBRATION IN A SEDIMENT TRANSPORT MODEL OF THE MIDDLE RIO GRANDE, NEW MEXICO

David Varyu, P.E., Hydraulic Engineer, Reclamation, Denver, Colorado, dvaryu@usbr.gov
Lisa Fotherby, Ph.D., P.E., Hydraulic Engineer, Reclamation, Denver, Colorado, lfotherby@usbr.gov

OVERVIEW

The purpose of this project is to develop a calibrated sediment transport and vegetation model for the Middle Rio Grande downstream of San Antonio (HWY 380 Bridge) to Elephant Butte Dam. Geomorphic conditions of flow, sediment transport, riparian vegetation and groundwater are linked in the SRH-1DV simulation. Hydraulics, sediment transport and groundwater conditions are defined by physical laws of nature, and the ecological factor, vegetation growth, is described by known plant response to the geomorphic factors. The establishment, growth and mortality of vegetation is tracked on a daily basis in response to dynamic physical conditions, and is tracked as individual plants located on every node at every cross section in the model (Fotherby 2012).

Model Description SRH-1DV is an adaption of SRH-1D, a one-dimensional mobile boundary hydraulic and sediment transport computer model for rivers and manmade canals. The base model simulates changes to rivers and canals caused by sediment transport. It can estimate sediment concentrations throughout a waterway given the sediment inflows, bed material, hydrology, and hydraulics of that waterway. Simulation capabilities include steady or unsteady flows, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport, and lateral inflows. It uses cross section based river information (Huang and Greimann, 2011).

SRH-1DV simulates the processes of seedling growth and mortality as a function of species type, changing river stage and groundwater level, the rate of root growth, and the potential for scour velocity. SRH-1DV tracks the potential for species-specific plant mortality due to drowning, velocity scour, and desiccation. The model assumes that the river has an abundant seed source. During the seed dispersal and germination season, the model assumes that seeds will germinate and begin to grow at all points above the wetted channel. A seedling is initially very vulnerable to mortality, but as it continues to grow, the plant becomes more resistant to the plant stresses induced by desiccation, drowning or scour and it increases the local hydraulic roughness of the channel. If a cottonwood seedling survives to an age of three years, the cottonwood tree then becomes very resistant to removal by scouring erosion (http://www.usbr.gov/pmts/sediment/model/srh1d/1dv/ index.html accessed December 2012).

MODEL INPUT DATA

The model input for SRH-1DV is the same as input for SRH-1D – channel and floodplain geometry, bed material gradation, sediment transport function, and boundary conditions – with the addition of vegetation inputs. The vegetation inputs include spatially defined age and vegetation coverage percentages, along with germination, growth, and mortality parameters for every vegetation type modeled. In addition to these input files, a GIS-based shapefile from vegetation mapping is required to define vegetation conditions (type and location) at the start of the simulation. A table in the vegetation input file translates the vegetation mapping classifications into the vegetation types (plants) simulated in the model.

Geometry The model spatial extent is from just upstream of the US-380 Bridge in San Antonio, NM to Elephant Butte Dam (Figure 1). The input geometry combines a portion of the 2002 ag-deg data set (Holmquist-Johnson, 2004; ~RM89-RM60), a 2007 bathymetric survey of Elephant Butte reservoir (Ferrari, 2008; ~RM41-RM27), and from various local surveys associated with the development of the Delta Channel into the pool of Elephant Butte Reservoir (~RM60-RM41). Every measure was taken to ensure a consistent vertical datum, however some survey data did not report a vertical datum and professional judgment was employed where necessary to convert all geometric data into NAVD88 elevations.

The input geometry data was developed in a HEC-RAS file and a series of discharges were run. Cross sections were edited as necessary in terms of adding levees, blocked obstructions, and ineffective flow areas to the model geometry to produce hydraulic conditions representative of actual flow patterns. For example, in areas where the channel is not in the lowest elevation of a cross section, levees are implemented in the model geometry to keep the water in the perched channel. A total of 196 cross sections were used in the model, including 159 measured cross

sections and 37 interpolated cross sections. Maximum cross section spacing was limited to 2500 feet, except in the lower end of the reservoir pool where the cross section spacing is irrelevant because the cross sections remain inundated by the pool.

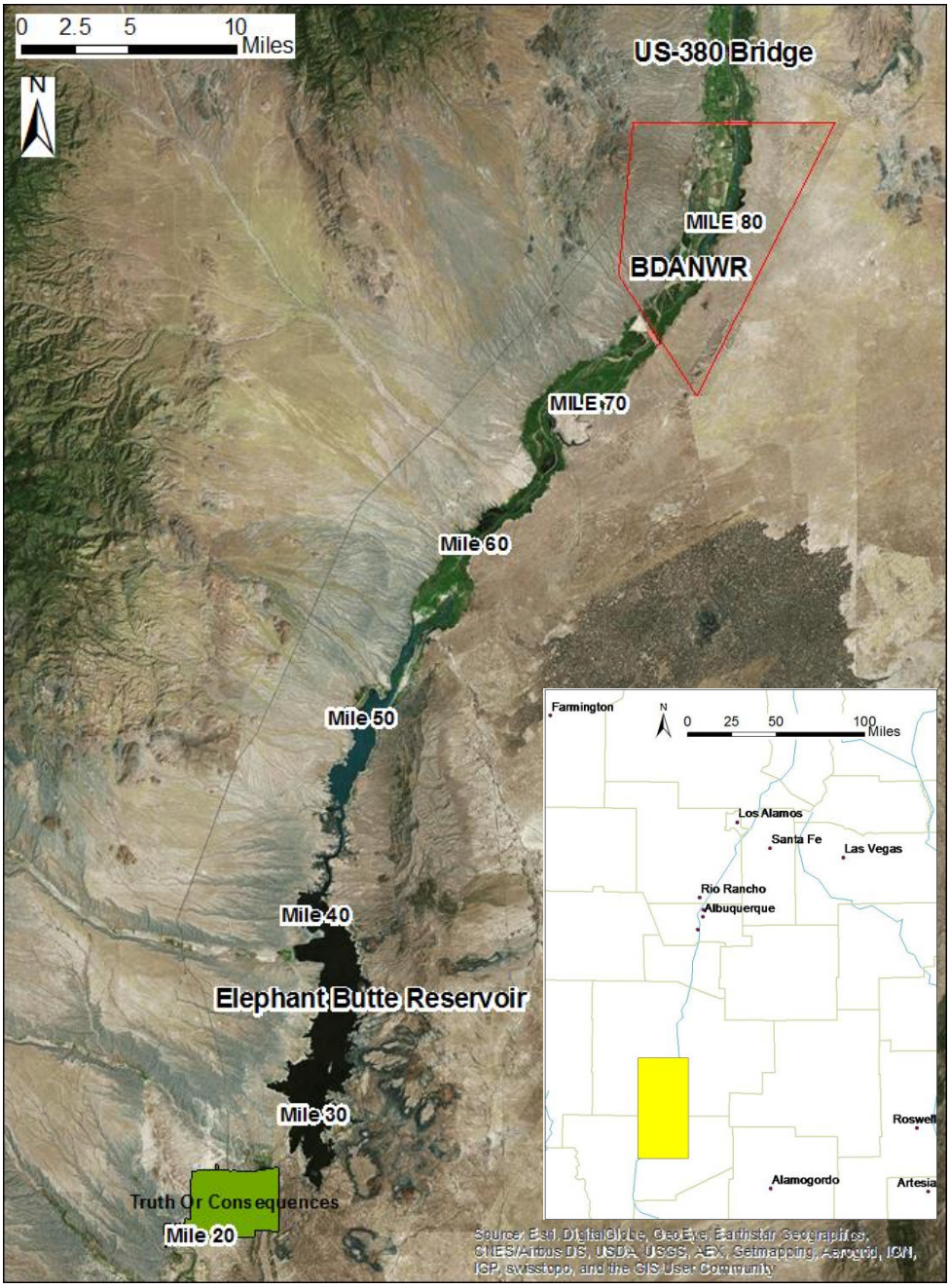

Figure 1 Overview map of model extent: US-380 Bridge to Elephant Butte Dam.

Bed Material and Sediment Transport Bed material data have been collected along the Rio Grande for various projects since the 1970s. Data appropriate for this model reach and time period were collected and prepared for model input. Twenty-eight sediment gradations are spatially assigned in the model, with the most downstream gradation located at EB-28 (~RM58). This gradation represents conditions for the model downstream of this point. The median grain size for the model domain is fairly uniform as compared to upstream reaches of the river, and a

range of 0.1 mm to 0.3 mm exists for all gradations employed in the model. The Engelund-Hansen transport formula is used in this model based on the size of the bed material in this spatial extent.

Boundary Conditions Boundary conditions need to be defined for the numerical model SRH-1DV. These include upstream conditions (flow rate and sediment discharge rate), downstream boundary condition (water surface elevation), and lateral flow and sediment contributions.

The temporal extent of this model begins in water year 2002 and ends with water year 2008. Daily discharge data from two USGS gages (08354800 Rio Grande Conveyance Channel at San Acacia, NM, 08354900 Rio Grande Floodway at San Acacia, NM) were combined to produce the upstream flow boundary condition for 10/01/2001 to 09/30/2008. The downstream boundary condition is defined as the water surface elevation of Elephant Butte Reservoir, and that daily data was transformed from local project datum to NAVD88 elevations. Figure 2 presents upstream boundary condition of incoming river discharge and the downstream boundary condition as the elevation of the Elephant Butte Reservoir pool.

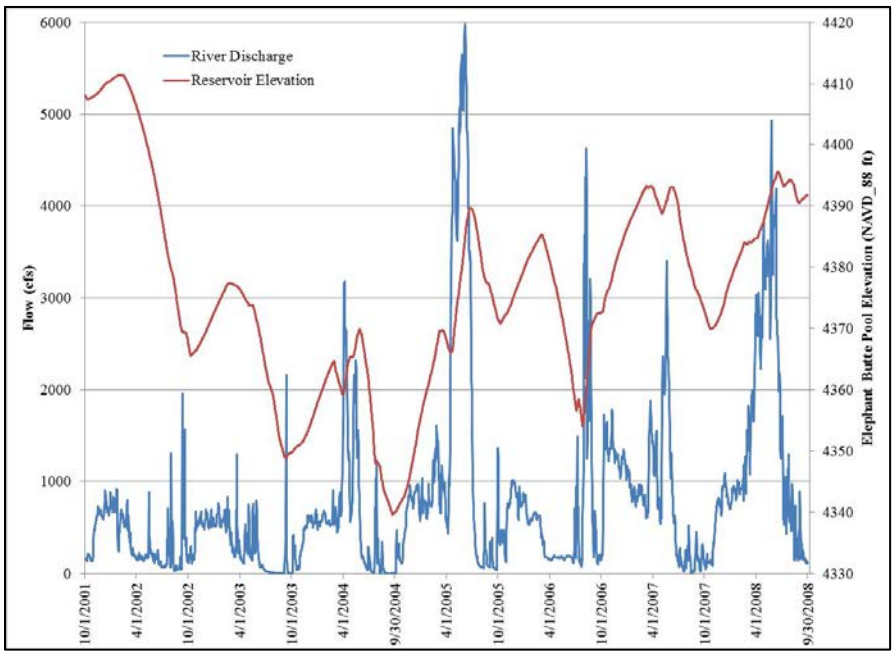

Figure 2 Downstream boundary condition; Elephant Butte Reservoir pool elevation.

The incoming sediment load at the upstream boundary of the model was developed by applying sediment rating curves based on dry, average, and wet flow regimes (Huang and Makar, 2012). Table 1 presents the classifications of the water year as Wet/Average/Dry, along with the coefficients a and b in for the power function rating curve sediment discharge to water discharge of the form $Q_s = aQ^b$.

Table 1 Water year type and sediment load coefficients used for upstream sediment supply.

Water Year	Flow Regime	coefficient a	coefficient b
2002	Dry	1.654	1.283
2003	Dry	1.654	1.283
2004	Average	2.895	1.229
2005	Wet	32.87	0.825
2006	Average	2.895	1.229
2007	Average	2.895	1.229
2008	Wet	32.87	0.825

Collins (2009) calibrated the gradation of the upstream sediment supply for the delta channel using published USGS data. Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) was used to process USGS suspended sediment concentration data along with bed material gradation data to produce the gradation of the total sediment load at the upstream end of the reach. Sediment load gradations are assigned for five unique discharges ranging from 500 cfs to 6000 cfs (Figure 2).

Significant tributary contributions of water and sediment do not reach the mainstem of the Rio Grande in this reach due to levees. No lateral flow or sediment inputs are included in this model.

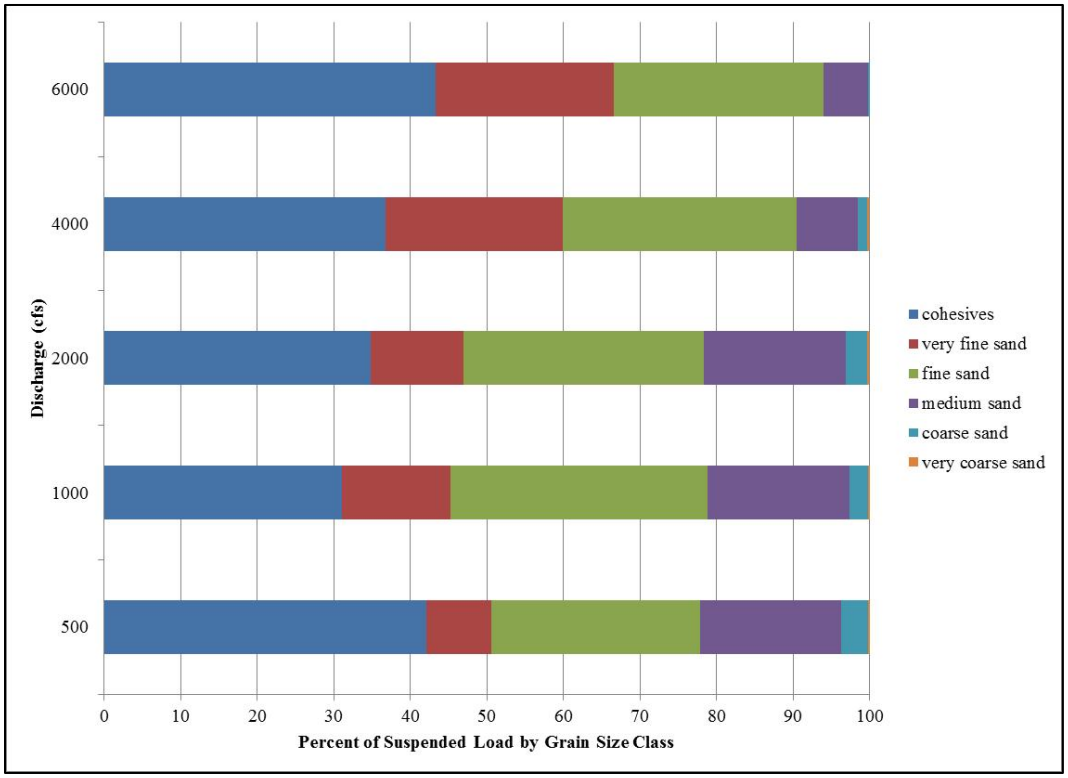

Figure 3 Changing gradation of upstream sediment supply as a function of discharge.

Vegetation data Vegetation was calibrated from initial to final conditions. The initial conditions were based primarily on the 2002 vegetation mapping (Callahan and White, 2004) which extends from upstream of this model domain to just downstream of river mile (RM) 62. Ancillary initial condition data from a 2004 vegetation map (Reclamation, 2005) was used as needed. The final conditions for the vegetation are derived from the 2008 vegetation mapping (Ahlers et al., 2010).

Discussion of Hink and Ohmart Classification and Interpretation The Hink and Ohmart (H&O) vegetation classification (Hink and Ohmart, 1984) was adapted and slightly modified by Reclamation biologists (Moore and Ahlers, 2003) while conducting habitat mapping for the southwestern willow flycatcher (SWFL), an endangered species. In general, the H&O system classifies vegetation based on species, height and whether there is a well-developed understory to supplement a canopy (overstory). Multiple vegetation species can be listed in the canopy/overstory and understory, where the first-listed species in the vegetation code is the most prevalent and the last listed is the least prevalent.

One of the modifications made by Moore and Ahlers (2003) was to try to better describe the vegetation density in 25% coverage increments. There were some methodological differences between the 2002 and the 2008 mapping, but in trying to maintain some consistency between the two datasets, they are interpreted and implemented as follows. The understanding during 2002 vegetation mapping was that nearly 75% vegetation coverage or more was needed for SWFL to find suitable nesting habitat. During the 2004 vegetation mapping, habitat occupations were

identified in areas where vegetation coverage was less than 75%, but still greater than 50%. The 2004 and 2008 vegetation mappings use a “d” indication (dense) at the tail end of the H&O classification to indicate vegetation coverage between 50-75%, where the 2002 data uses an “f” indication (full) for vegetation coverage greater than 75%. There was also an “s” indicator that was meant to indicate ‘sparse’ or ‘scattered’ (USACE et al., 2007), and the appropriate interpretation of this is unclear. For an area to be identified as ‘covered’ with vegetation there needs to be at least 25% coverage. It was assumed for this study that an identified area with an “s” qualifier was the same as if there was no qualifier.

A comparison of initial vegetation coverage (2002 and 2004 mapping) to final vegetation coverage (2008 mapping) includes 461 unique vegetation classifications, including a classification for no-grow areas (roads, railroad track) and open water areas (river and reservoir). Each unique vegetation classification can be one of 4 different density variations. For example, a lone stand of salt cedar, 5-15 feet high (H&O structural Type 5), can be sparse or scattered (s), dense (d), full (f) or have no density indicator.

Modified Hink and Ohmart Applied to SRH-1DV Input Transferring initial vegetation conditions defined by vegetation mapping classifications to the vegetation types and cross section locations simulated in SRH-1DV model requires some interpretation. In the modified H & O vegetation classification system, it is not uncommon to have the same vegetation type at two different ages in the same classification. A mature cottonwood can be present in the canopy and younger trees may form part of the understory. The SRH-1DV model does not simulate or track two of the same vegetation types on a single point. It was therefore necessary to have two vegetation types to represent the same species at different ages; one older and taller for the canopy, and one younger and shorter for the understory. This was not necessary for grasses or cattails as their maximum height does not exceed 15 ft. To ensure that twice as many germinations are not produced in SRH-1DV, only one age class for a given species is allowed to germinate. The younger category of a given species was arbitrarily assigned the ability to germinate, even though the older stands of some species, such as cottonwoods, would be more likely to supply seeds.

Vegetation mapping is normally classified by plant height (H&O vegetation structure) while vegetation modeling is based on plant age with plant height as a function of age. Fotherby (2012) provides growth rates for the vegetation types by age. These growth rates were used to translate vegetation height (H&O vegetation structure) into an age (SRH-1DV input).

Simulated Vegetation Types The model has to be able to distinctly represent a species’ characteristics and responses to environmental conditions to justify simulation in this riparian vegetation model. Only riparian species that are frequently dependent on the water table for moisture can be well simulated; the species simulated in this Rio Grande model are Fremont cottonwood, Gooddings black willow (tree willow), sand bar willow (coyote willow), mulefat (seep willow), honey mesquite, cattail, Russian olive, tamarisk (salt cedar), and grasses (grass is a generic grouping of herbaceous and drought resistant upland grasses that provide ground cover) (Fotherby, 2012). Although there are many more species in the area, the number of simulated species is limited. There are a large number of parameters required for each species and all parameters cannot be calibrated or verified in each model. Fremont cottonwood is used here to represent cottonwoods, sand bar willow and mulefat are the representative riparian shrubs, honey mesquite is also assigned for screwbean and common mesquite, Russian olive is also assigned for New Mexico olive, only one tamarisk is simulated, and the only herbaceous representation is an upland grass that is resistant to desiccation. Roads and railroads are simply ‘no-grow’ zones.

Using two vegetation ‘types’ for different ages of the same species (older/taller and younger/shorter) as well as a no-grow designation (no plant establishment permitted) yields a total of 17 vegetation types: seven with two age/height classes, two with one age/height class, and the ‘no-grow’ vegetation type. A description of these vegetation types and references for SRH-1DV parameter selection are presented in Fotherby (2012).

Assigning Density to Initial Conditions Initial vegetation conditions in the model are also assigned from density reported in vegetation mapping. Vegetation densities in the modified H&O classification system are broken down in 25% vegetation cover increments. An ‘open’ polygon in the 2002, 2004, and 2008 vegetation mapping would indicate that there is less than 25% coverage, and the indicators “d” and “f” indicate 50-75% and 75-100%, respectively, where no indicator implies 25-50% vegetation cover. This is the total percentage of vegetation cover, regardless of how many species are present or listed in the category. Certain assumptions were made to implement the modified H&O information into a format suitable for SRH-1DV. First, vegetation densities for a given mapped

polygon are set at 37.5%, 62.5%, and 87.5%, depending on the presence/absence of an indicator ("d"/"f"). Second, the breakdown of relative percentages is based on their order as specified in the H&O classification method.

Table 2 presents the breakdown of implemented vegetation cover based on the number of species defined in each structure layer (canopy/overstory, or understory) of the vegetation code.

Table 2 Distribution of vegetation cover by code indicator and number of vegetation types.

	Number of vegetation types listed				
Total%	1	2	3	4	Total
25-50 (regular)	37.5				37.5
	20	17.5			37.5
	15	12.5	10		37.5
	12.5	10	7.5	7.5	37.5
50-75 (d=dense)	62.5				62.5
	33.3	29.2			62.5
	25	20.8	16.7		62.5
	20.8	16.7	12.5	12.5	62.5
75-100 (f=full)	87.5				87.5
	50	37.5			87.5
	35	30	22.5		87.5
	30	22.5	17.5	17.5	87.5

Vegetation Calibration Methodology The 2002, 2004, and 2008 vegetation maps used as model inputs and comparisons for model outputs are based on aerial percent coverage. The methodology used in this calibration process is based on percentages of model nodes (cross section points) located within a polygon. The assignment of vegetation species onto SRH-1DV model nodes is based on the polygon where the node is located and the percent vegetation cover specified in the input file. The number of nodes assigned a given vegetation type will be as close to, without exceeding, the assigned percent cover, or density.

The assessment of the model output worked in a similar manner. The model output reports a set of predicted vegetation types existing on every model node. Nodes are allowed to have more than one vegetation type, so the number of rows in the main model output text file equals the product of the number of model nodes multiplied by the number of vegetation types. The model nodes are located within the appropriate 2008 vegetation mapping polygon and the model outputs are compared to the observed data as recorded in the 2008 mapping polygons. The model comparison is not cross section based but rather polygon based since there are usually multiple segments of cross sections within a given polygon.

MODEL CALIBRATION

For this project, the ability to calibrate the sediment transport is important only in terms of being able to calibrate the vegetation data. For example, being able to exactly match the channel degradation due to the drop in Elephant Butte Reservoir elevation (base level lowering) is not necessary as long as the modeled degradation is sufficient to lower the water table elevation in the area and allow simulated vegetation mortality due to desiccation.

Almost half of the species for this Rio Grande study are being modeled for the first time in SRH-1DV. The parameters for each species are selected from a range of values identified in a literature review. Many parameter values required adjustment during calibration. Growth rates, germination seasons, dormant seasons and drought and inundation tolerance can all vary with regional climate differences and parameters from previous applications in different regions may not be suitable for the Rio Grande. The large number and detailed assignment of modified

H&O classifications for initialization of this model are another reason for a calibration investigation. The maximum spacing between cross section points was limited to 25 feet to ensure every vegetation polygon was represented by a model node. The number of model nodes is 66,198 for the model domain.

Through the course of the calibration process, adjustments were made to germination, growth, and mortality parameters for various plant species. A list of significant changes to the initial parameters (as defined by Fotherby 2012) is followed by a discussion of the final calibration results.

All Vegetation Types

- The model input competition tables are set up to define at what age a species will be out-competed by other species/age combinations. Therefore, each competition table was adjusted so that young tamarisk would out-compete other young vegetation types (further discussion of this adjustment below).
- Dormancy period extended from December 1 through January 1 to October 1 through March 31.

Mulefat

- Scour velocity needed to remove new and one year old plants reduced by one-third (to 0.67ft/s and 1 ft/s respectively).

Tamarisk

- Germination period extended from July 1 through September 30 to March 14 through November 15.

Upland Grass

- Scour velocity needed to remove new, one, and two year old plants reduced by one-half (to 1ft/s, 1.5ft/s, and 2ft/s respectively)

The list above does not encompass all of the iterations attempted in the calibration process, but only a summary of the changes between the initial set of vegetation parameters and the best-fit calibration parameters. The interpretation and implementation of the H&O classification system to SRH-1DV was at least as involved a process as calibration of the germination, growth, and mortality parameter for the vegetation species.

Vegetation Calibration Results There are 808 mapped polygons included in the calibration analysis. The final analysis methodology calculated the difference in percent coverage for all vegetation types within four different height categories (associated with the H&O structure classification): 0 to 15 feet, 15 to 20, 20 to 40, and over 40 feet. For the nine species being modeled (not counting the 'no-grow' vegetation type), there are 36 species/height categories being considered per polygon. The most common error is in the 0 to 15 feet range for all species except for Gooddings black willow (tree willow) and mesquite. This indicates that the germination process is a likely source of the most error in the simulation. Figure 4 shows the count of which age class represents the highest percent error per species per polygon.

If we consider the error of each vegetation type across the 808 vegetation polygons, we can discretize the error based on how many model nodes are within each polygon. Table 3 presents the grouping of polygons based on the number of model nodes within that polygon. The one polygon within the range "Q" is a polygon classified as "open water" and is the continuous riverine and reservoir polygon in the model, and the upper bound of this range was selected such that the midpoint of the range equaled the number of model nodes in this polygon.

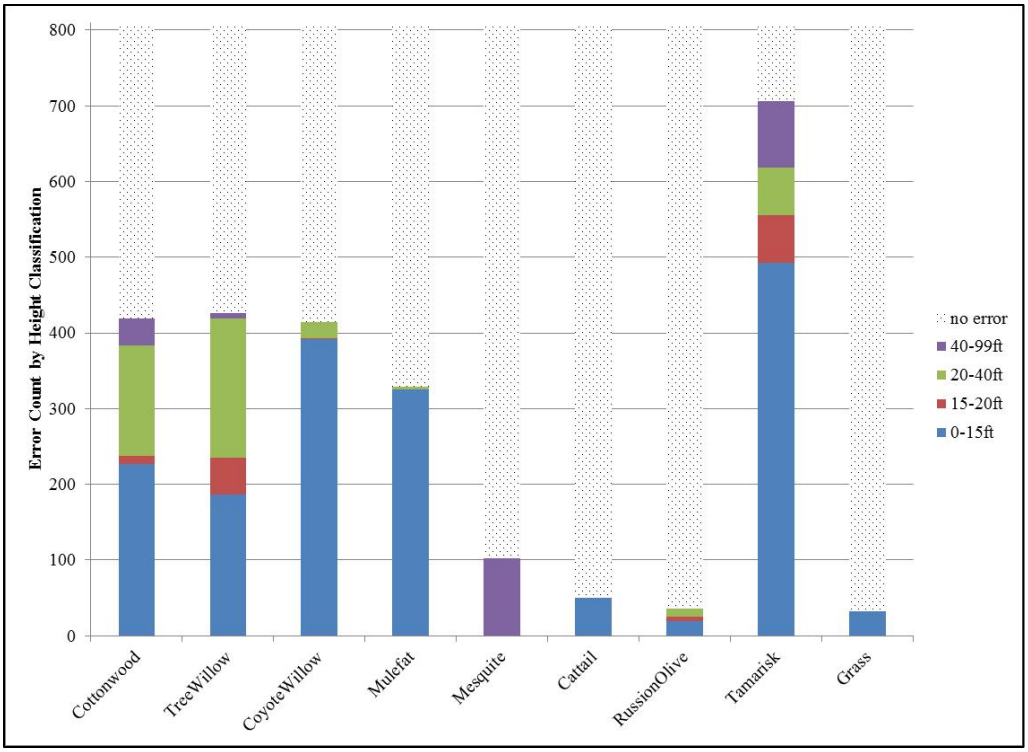

Figure 4 Count of age class representing the highest error per species polygon.

Table 3 Bin ranges used in analyzing error by number of model nodes in mapping classification polygons.

Range ID	Min Model Nodes	Max Model Nodes	Count Polygons in Range
A	1	5	116
B	6	10	132
C	11	20	168
D	21	30	125
E	31	40	63
F	41	50	44
G	51	60	31
H	61	70	25
I	71	80	11

Range ID	Min Model Nodes	Max Model Nodes	Count Polygons in Range
J	81	90	7
K	91	100	8
L	101	200	42
M	201	300	13
N	301	400	13
O	401	500	3
P	501	600	6
Q	601	29586	1

Figure 5 presents the average maximum absolute error (of the four height classifications) by vegetation type relative to the midpoint of the bin range. For example, consider the "O" bin range. There are three polygons that contain between 401 and 500 model nodes. If we consider just tamarisk, the maximum error for two polygons was in the 0 to 15 ft height range (-70% and 59%), and for one polygon was in the 40-99 ft height range (error of -25%). A negative error means SRH-1DV is predicting too much of a vegetation/height combination and a positive error indicates not enough of that vegetation/height combination is being predicted. The average of the maximum absolute error for tamarisk for the three polygons containing between 401 and 500 model nodes is 52%. This point is the peak error in Figure 5. The results in Figure 5 show good calibration (considering measured data specified in 25% bins), with tamarisk being the species that was least successfully calibrated. Another way to look at the calibration results is to consider the average (over the bin range) of the average error of the four height classifications for one

vegetation species. This is simply the average error of all 12 (four height classes by three polygons) error values associated with a bin range. Figure 6 presents the average error for each vegetation species by bin range.

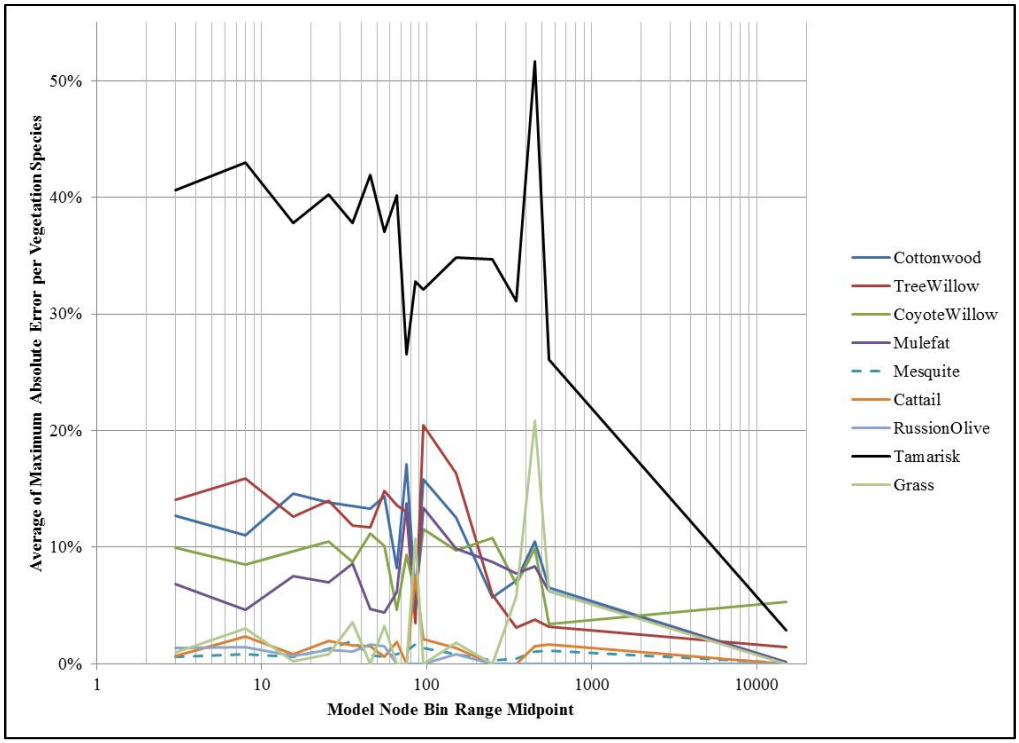

Figure 5 Plot of average of maximum error per vegetation species.

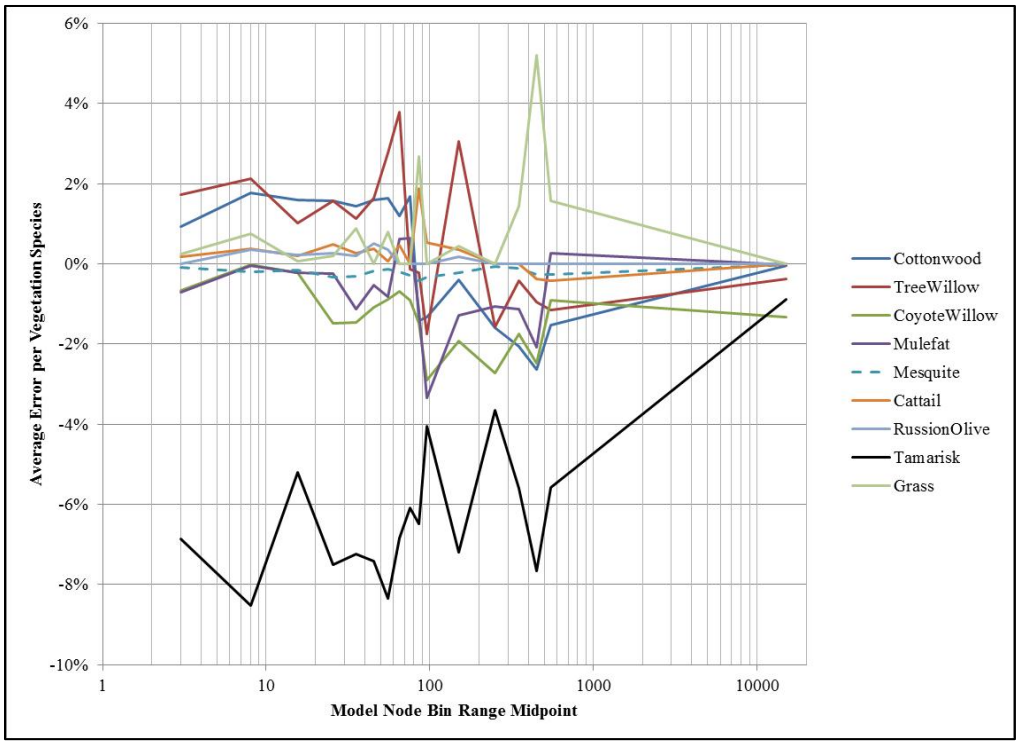

Figure 6 Average error per vegetation species.

These differences can be represented visually using ArcMap. Instead of trying to combine errors by bin ranges as was done above, the actual error for a given polygon can be presented for one vegetation species and height classification at a time. A python script was developed as a tool to translate SRH-1DV output text files into visually represented error polygons. Figure 7 presents an example plot that can be made for any combination of vegetation species and height classification, in this case Tamarisk for 0-15 ft (selected polygons outlined in cyan). The color coding is constructed in absolute terms and all errors that are negative are hatched horizontally while positive errors are hatched vertically.

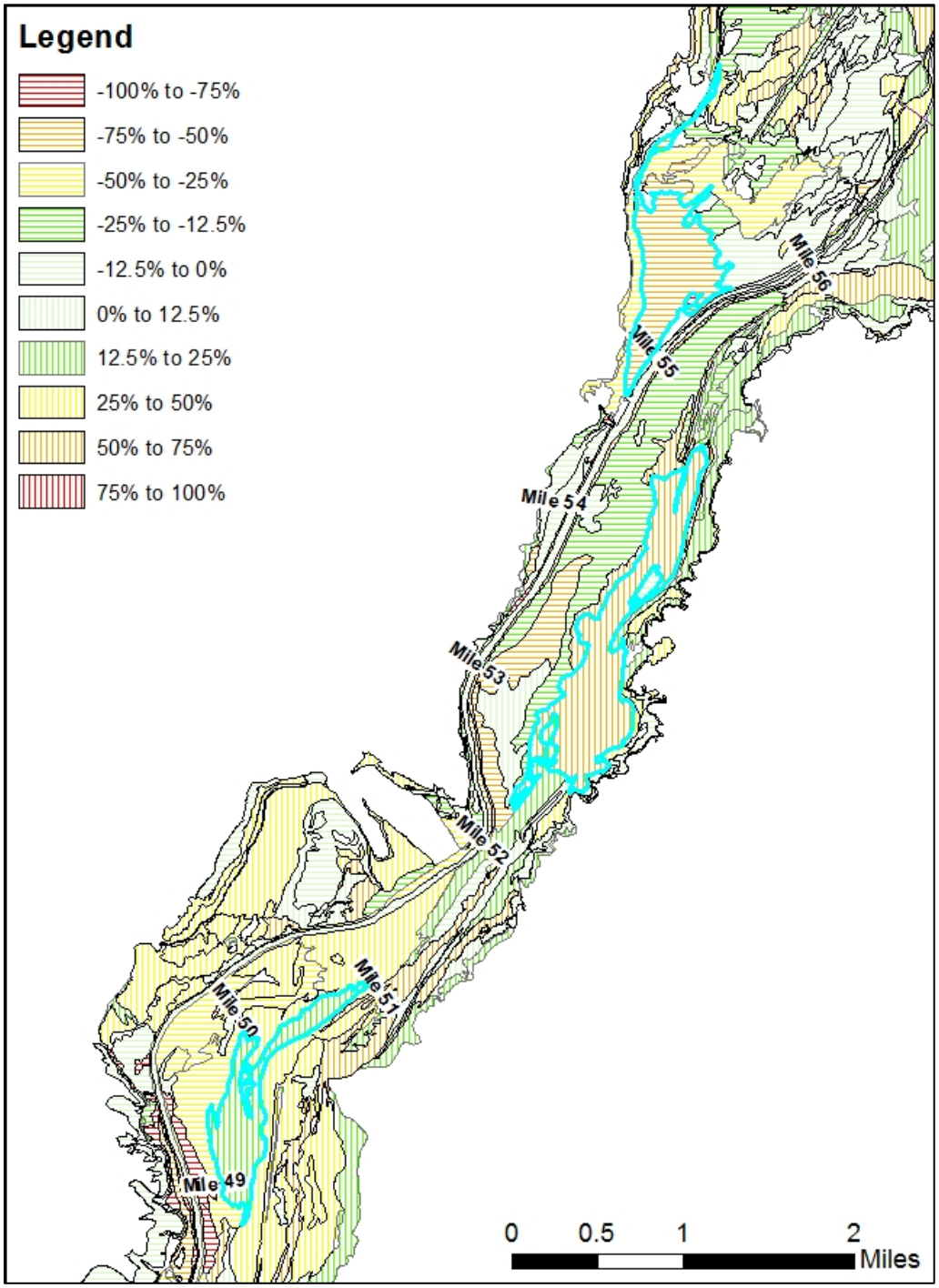

Figure 7 Vegetation polygons attributed by error in percent coverage for Tamarisk, 0-15 feet tall.

MODEL LIMITATIONS, ERROR SOURCES, AND AREAS OF IMPROVEMENT

This model, as with any, contains errors; some of which are due to data availability, some of which are due to limitations to the SRH-1DV model, and some are areas that could be improved (further calibrated) with more time and effort. A brief list describing some potential improvements follows:

- **Mapping inconsistencies**: In some instances the dominant canopy species for a 2008 polygon is not identified at all for the associated 2002 polygon.

- **Growth rates** are input into the model based on age and month of the year only. A wet year could allow for more tree growth (stalk diameter) than a dry year. The model could be adjusted to allow for this.

- **Lateral channel adjustment:** Some errors in the simulation are due to the fact that channel width change and lateral migration are processes not modeled in the 1D framework.

- **Anthropogenic influences:** channel excavation conducted by heavy machinery, channel clearing to increase morphodynamic response, and vegetation planting during habitat improvements are all actions taken on the river but are not simulated in the model.

- **Groundwater module:** the groundwater module is relatively coarse in the SRH-1DV. One soil type is incorporated in the Rio Grande model with one hydraulic conductivity value for the floodplain sediments, although two input types are allowed. This is a gross assumption, yet necessary as the data needed for accurately mapping hydraulic conductivity for this large area would be monumental.

- **Salinity:** Salt cedar (tamarisk) is considered a disturbance species, where it doesn't necessarily out-compete native species, but is able to take advantage of conditions where native species cannot survive (including high saline environments, hence the name). To overcome salinity not being simulated, tamarisk was modeled as a relatively competitive species, even though literature describes is as non-competitive. In this way, a native species that would not be able to germinate in the real world due to some level of salinity in the soil, is modeled as being outcompeted by salt cedar in SRH-1DV. The end result in the model is similar to reality, where the native species would not establish but salt cedar would. Incorporating salinity would make SRH-1DV more data intensive and it may not prove beneficial. Manipulating the competition table appears to be an appropriate surrogate for salinity modeling.

- **Interpretation of the modified H&O Vegetation data:** Implementing some bounded random number generator into SRH-1DV could allow for multiple vegetation age/heights to be assigned to model nodes according to the height range specified by the H&O classification system. Also, there are four density ranges from the modified H&O system at 25% increments. Similar to age, a random number generator could be implemented either within SRH-1DV or in the input file generation where the vegetation density could be any value as long as it was within the appropriate 25% range. It would be necessary to develop many simulations using the random number generators and statistically evaluate the outputs to determine if the central tendencies predict the observed end condition reasonably well.

CONCLUSIONS

The calibration of multiple species within SRH-1DV to the Middle Rio Grande was completed with good accuracy. The average error for all species/age combinations was well within the accuracy of the measured data. Further calibration may prove useful. In addition, a methodology for processing, presenting, and interpreting SRH-1DV results using ArcGIS has been developed and can be easily applied to future model runs.

Additional calibration, if conducted, would involve identifying the mode of mortality for all species within the model spatially and determining if that mechanism is being appropriately simulated. Germination would be looked at as well to see if plants are not only establishing in the right quantities but also identifying the mechanisms as to why establishment is or is not occurring in certain areas. Conducting multiple simulations using a bounded random

number generator to assign vegetation age and density appropriate to the H&O classification system would be another option in further calibration of SRH-1DV to the Middle Rio Grande.

A recent vegetation mapping using the H&O classification system was completed in 2012 and the final product will soon be available. Conducting a model validation for the period of 2008 to 2012 would provide insight as to the effectiveness of the model calibration and would help refine values assigned to various vegetation germination, growth, and mortality parameters. If the validation proves successful, then further calibration may not be necessary. The vegetation model, whether or not further calibration and validation are pursued, can be used for analyses of the effects of potential river maintenance actions and/or water operations. Absolute predictions of future conditions may not be a proper application of this model but rather a relative ranking of the effects in terms of sediment transport and vegetation conditions could be accomplished by employing this model.

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