HABITAT AVAILABILITY VS. FLOW RATE FOR THE PECOS RIVER, PART I: DEPTH AND VELOCITY AVAILABILITY

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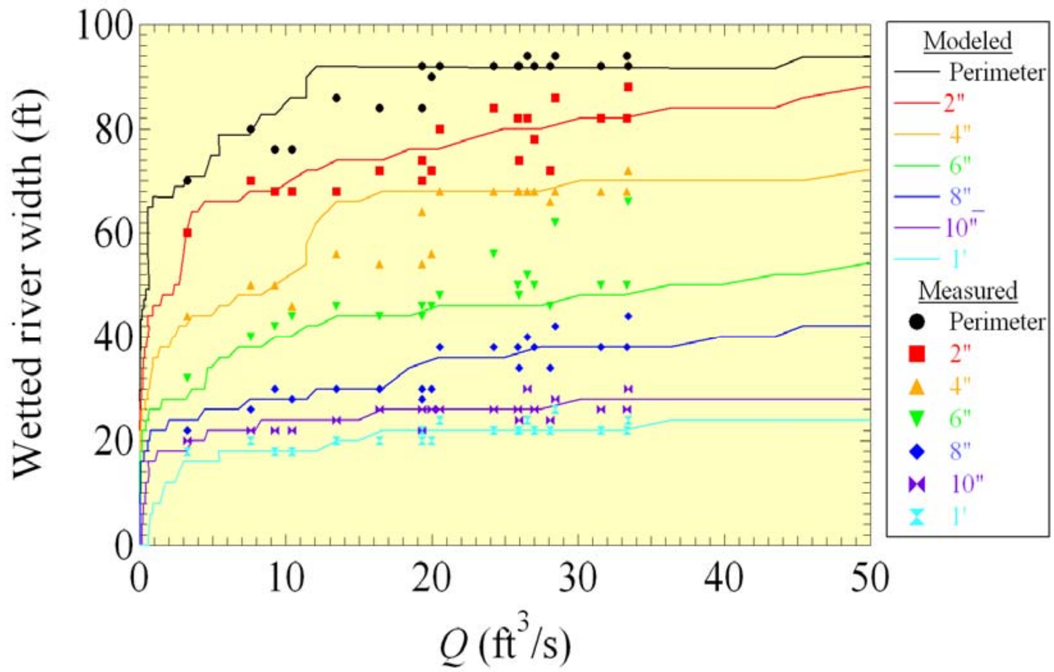
The waters of the Pecos River in New Mexico must be delivered to three primary users: (1) Pecos River Compact—each year a percentage of water from natural river flow must be delivered to Texas; (2) Agriculture—Carlsbad Irrigation District has a storage and diversion right and Fort Sumner Irrigation District has a direct flow diversion right; and (3) Endangered Species Act—an as yet unspecified amount of water is to support Pecos Bluntnose Shiner Minnow (PBSM) habitat within and along the Pecos River. Currently, the US Dept. of Interior Bureau of Reclamation, the NM Interstate Stream Commission, and the US Dept. of the Interior Fish and Wildlife Service are studying the PBSM habitat preference. Preliminary work by Fish and Wildlife personnel in the critical habitat suggest that water depth and water velocity are key parameters defining minnow habitat preference. However, river flows that provide adequate preferred habitat to support this species have yet to be determined. Because there is a limited amount of water in the Pecos River and its reservoirs, it is critical to allocate water efficiently such that habitat is maintained, while honoring commitments to agriculture and to the Pecos River Compact. This study identifies the relationship between Pecos River flow rates in cubic feet per second (cfs) and water depth and water velocity.

BACKGROUND

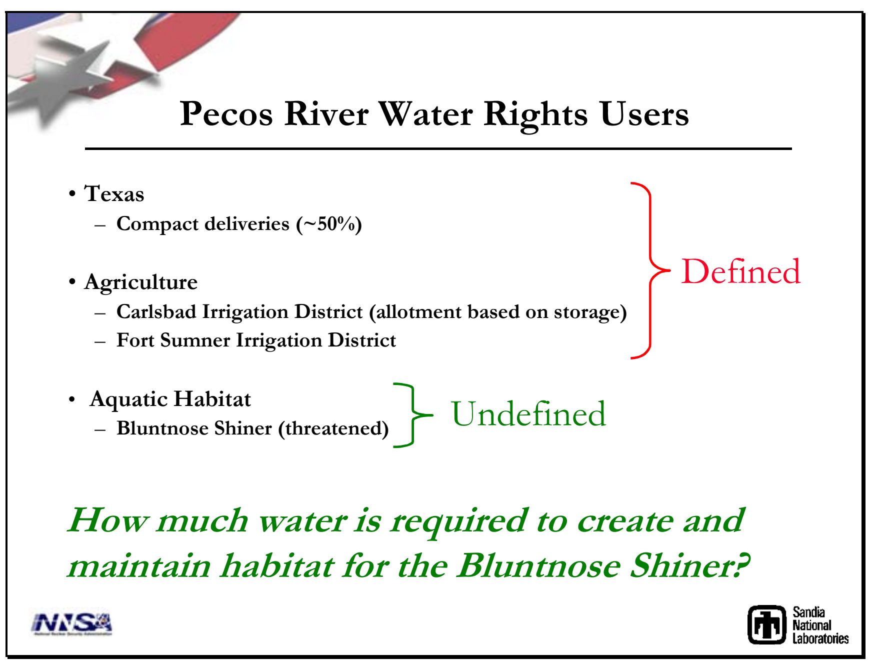
River bathymetries will be used as input for a modeling technique recently developed by Sandia National Laboratories. The model predicts water depth, wetted area, wetted perimeter, velocity, and sediment activity as a function of river discharge based on data collected at 2-foot increments across the river. Model results are validated by field measurements at each transect. Depth, velocity, and sediment activity availability curves will yield detailed information of PBSM habitat availability across a given transect as a function of river discharge. The model can be further extended to give total linear width of river or wetted area that meets particular/preferred PBSM habitat requirements.

The purpose of this work is to determine what fraction of the Pecos River width is suitable for the PBSM habitat for any given flow rate. Because the Pecos River is an ephemeral, braided river, it is likely that there exists a specific flow rate that exhibits a point of "diminishing returns." For example, perhaps doubling flow rate serves only to increase the available PBSM habitat by 10%. This study identifies the optimum flow rate that presents the PBSM with the most habitat with the least flow ('bang for the buck').

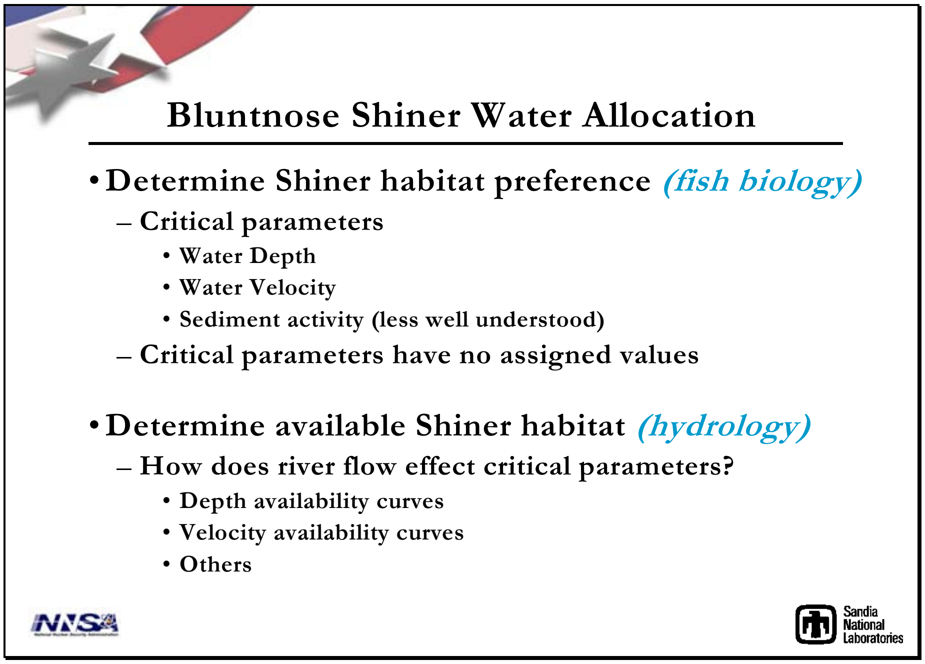
The figure below is an example depth-availability plot for the Pecos River at Pipeline Crossing. Both data collected (symbols) and modeled depth availability (curves) are shown. The plot may be read as follows: Consider, hypothetically, that a species of fish prefers a habitat of 6 in. The width of river that is at least 6 in. deep is read using the green curve by noting the wetted river width and flow rate at any point along it. For example, the width of the river (perimeter or black line) is approximately 85 ft at a flow rate of 10 cfs (find the intersection of a vertical line from 10 cfs with the black depth-availability curve). Note also that green line indicates at least 6 in. of depth for 44 ft (52%) of the river width at 10 cfs. Let us examine the effects upon this available habitat after doubling the flow to 20 cfs. The width of the river increases to 92 ft and the width of the river that is at least 6 in. deep increases to 50 ft (54% of the river width). Doubling the flow rate at this stretch of river serves to add only 6 ft of 6-in deep habitat (a 2% increase in relative width). Clearly, there is a point of diminishing returns, and biologists and water regulators will need to compromise between the amounts of water flowing in the river and the width of habitat yielded.



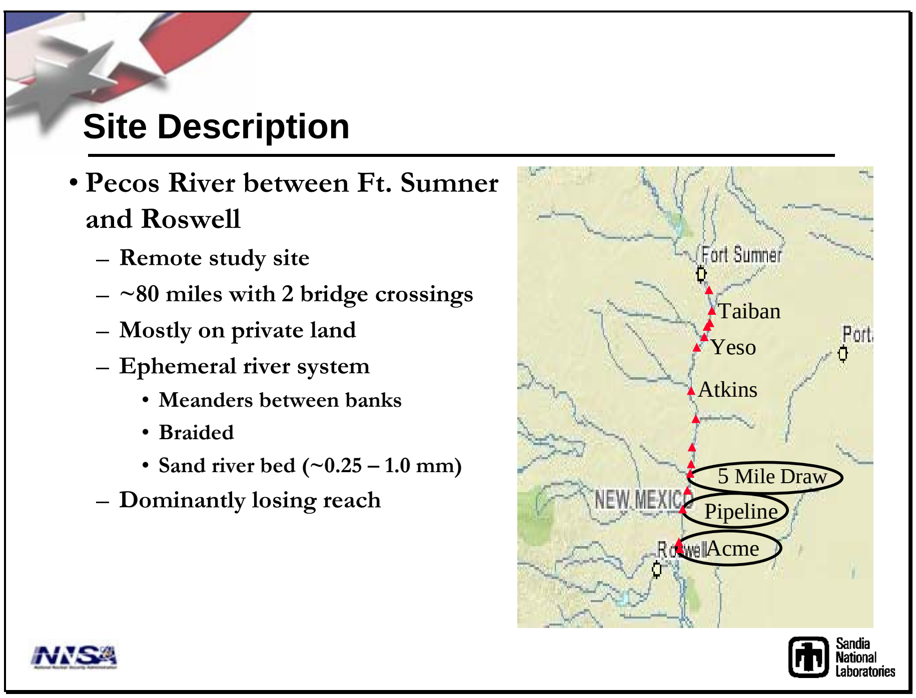
This work was funded through Sandia National Labs Small Business Assistance Program in support of helping Carlsbad Irrigation District farmer/rancher members understand and overcome the technical challenges that hindered economic development associated with lack of Pecos River flow



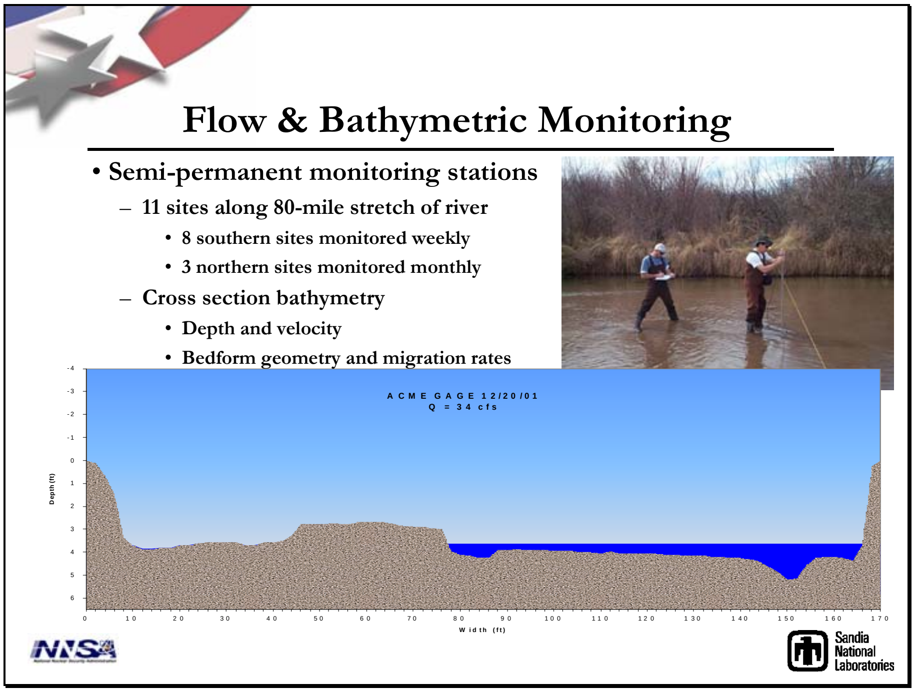
The three primary users of surface water on the Pecos River are Texas, New Mexico agriculture, and riverine wildlife. Currently, their exists means by which to calculate water allocation to/for Texas and NM Agriculture but the water need by wildlife is less well understood.



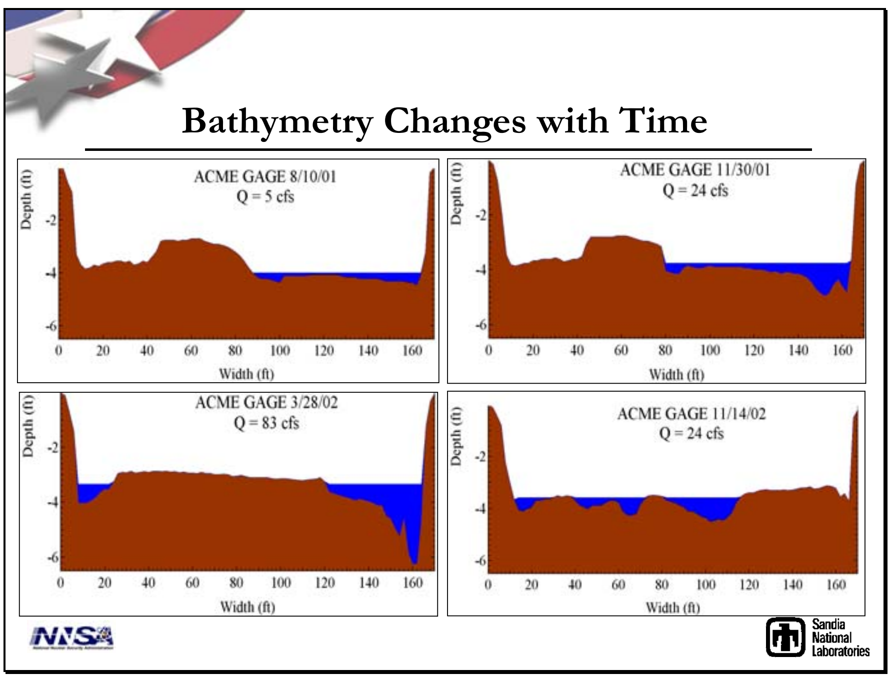
Determining water allocation for the Pecos Bluntnose Shiner Minnow (PBSM) requires, at a minimum, two distinct skill sets. First, fisheries biologist must describe the preferred habitat of the PBSM (potentially in terms of preferential water depth, velocity and sediment activity regimes). Second, surface water hydrologists must then determine how much preferential habitat is created as water flow down the Pecos River is increased/ decreased (must describe available habitat as a function of river flow intensity). Ultimately, this two distinct and separate data sets would need to be reviewed by state water managers and a target flow set that maximizes habitat with minimum river flow. Sandia has performed a detailed analysis of habitat availability.



The river section studied here is predominantly a losing reach. Therefore, the southern sites are most likely to have reduced flows that could potentially negatively impact PBSM habitat. The rest of the presentation will focus on and show examples from the three circled sites in the southern portion of the field site.



Measurements were of water depth a velocity at 2 foot increments across the wetted portion of the river. On dry land, measurements were made from the reference height to the dry sand surface, completing the bathymetric profile. A 2-D view of a river cross-section is shown below. When the water clarity permitted, 3-5 measurements of either dune or ripple height, frequency and migration rate were also recorded across the wetted river channel.



Approximately 32 field trips were made between August 10th, 2001 and November 14th, 2002 at the southern sites. The bottom of the Pecos River is generally composed of sandy sediments that are to some degree almost always active. This slide shows four snapshots in time over that period demonstrating the changes in river bed profile as function of time. These snapshots are all looking upstream from the ACME Gage. The original presentation contained a movie clip showing all 32 field collections.

Creating Availability Curves

- **Manning Relation**

$$Q = 1.49 \frac{A^{\frac{5}{3}} S_b^{\frac{1}{2}}}{P^{\frac{2}{3}} n}$$

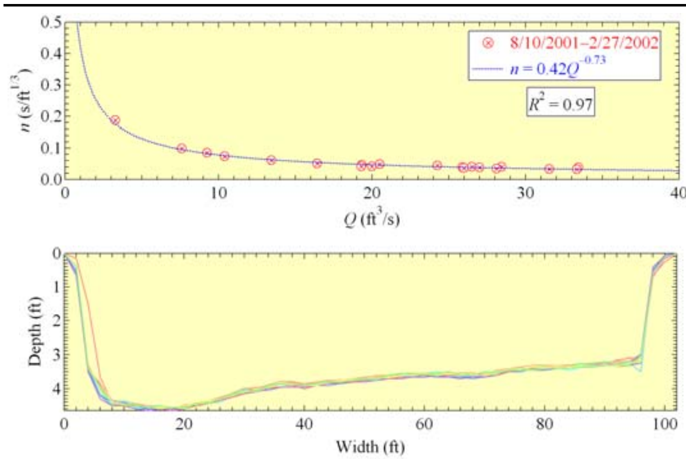
Q = flow rate
A = wetted area
P = wetted perimeter
S_b = water slope
n = Manning roughness coefficient

– ***A*, S_b, *P*, and *Q* are measured during monitoring, therefore we can solve for *n*.**

$$n = 1.49 \frac{A^{\frac{5}{3}} S_b^{\frac{1}{2}}}{P^{\frac{2}{3}} Q}$$

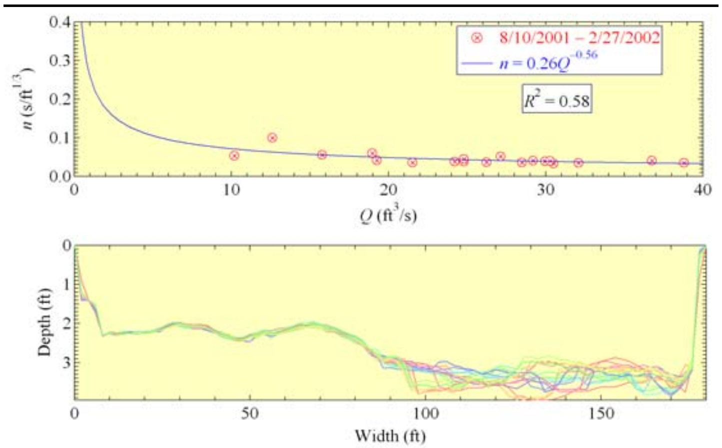
The model is based on the empirical Manning's relation. The only parameter not directly measured in the field was the manning friction factor and therefore was back-solved.

Manning Roughness Coefficient at TPLC



The upper plot shows Manning's friction factor as a function of river flow rate at the Pipeline Crossing Transect. There exists a strong power law relationship between n & Q with a high degree of accuracy. The high accuracy is in large part due to the fact that the river bed profile (bottom) was extremely constant over the time period described here. Also, this site contained the flattest slope & most consistent flow regime of all field sites.

Manning Roughness Coefficient at T5MD



The upper plot shows Manning's friction factor as a function of river flow rate at the Five Mile Draw Transect. There again exists a decent power law relationship between n and Q, but in this case the accuracy is reduced. The lesser accuracy is in large part due to the fact that the river bed profile (bottom) was extremely inconstant over the time period described here. Closer inspection would show that the thalweg or deep section of the river that carries most of the water is translating laterally across the wetted river channel. This transect has a steeper slope and the flow conditions were slightly more irregular than at TPLC.

Model Calculation

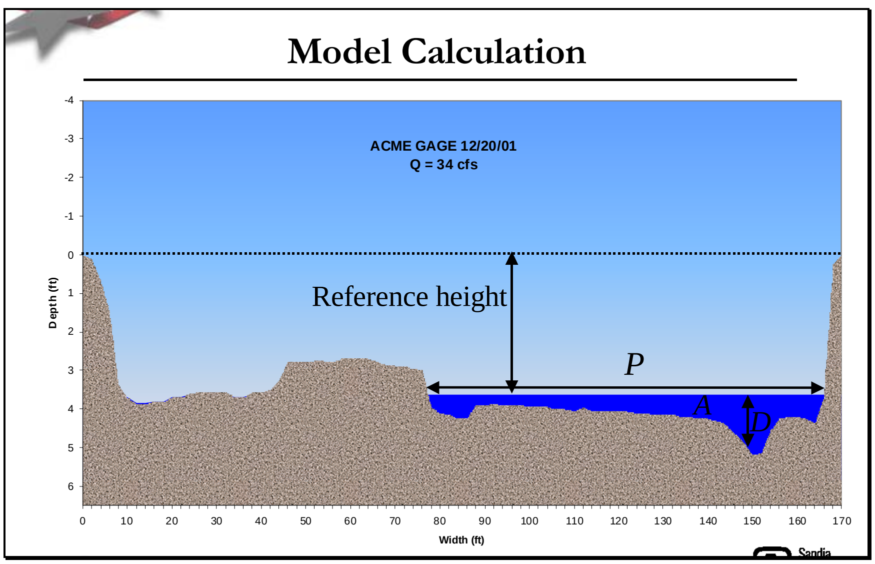
Remember that → $Q = 1.49 \dfrac{A^{\frac{5}{3}} S_b^{\frac{1}{2}}}{P^{\frac{2}{3}} n}$

Determined a constitutive relationship between Q and n → $n = \alpha Q^{\beta}$

Which results in →

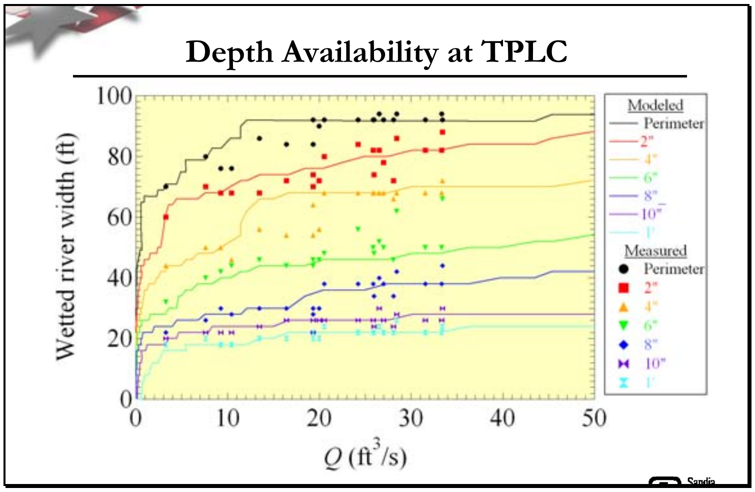
$$Q = \left[\frac{\left(1.49 \dfrac{A^{\frac{5}{3}} S_b^{\frac{1}{2}}}{P^{\frac{2}{3}}} \right)}{\alpha} \right]^{\frac{1}{1+\beta}}$$

Once the power law relationship was developed between n and Q, it was reinserted in the original Manning's relation.

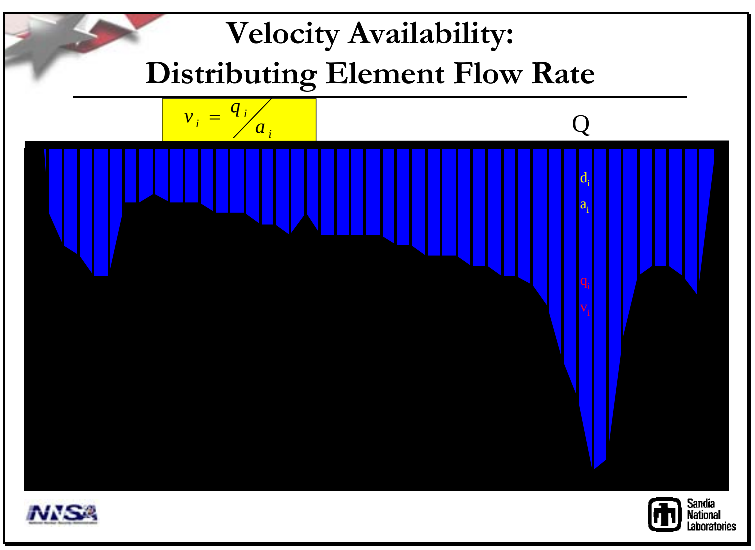


Once a characteristic or representative bathymetry is identified for each transect, the next step in model development is to calculate the flow rate and hydraulic geometry as a function of river stage. A horizontal line connecting the tops of the permanent markers on either side of the river denotes the reference height from which the model calculates the river stage. The maximum reference height at each transect is equal to the vertical distance from permanent markers to the lowest point of the characteristic or representative bathymetry (e.g., approximately 5 ft in the graph above). A reference height (depth) of zero corresponds to the bank-full water level (maximum river discharge); as the reference height increases downward towards the sediment bed, river discharge (calculated as the flow through a transect's characteristic bathymetry below the reference height) decreases. The model may be run deterministically when a user chooses an initial depth (river stage) seeking to find the corresponding flow rate. For example, if the reference height is 3 ft (draw a horizontal line across the figure above at 3 ft), the water level is set three feet below the reference line and the model calculates the wetted area, wetted perimeter, and flow rate through the wetted cross-section. Specifically, the characteristic bathymetry is divided according to the 2 ft (0.6 m) distances between the measurement stations (hereinafter referred to as 'elements'). The wetted area is calculated by determining the average water depth of each element (average depth of two adjacent stations), calculating the area of each water element (multiply the average depth by the distance between depth measurements, i.e. 2 ft), and summing the results.

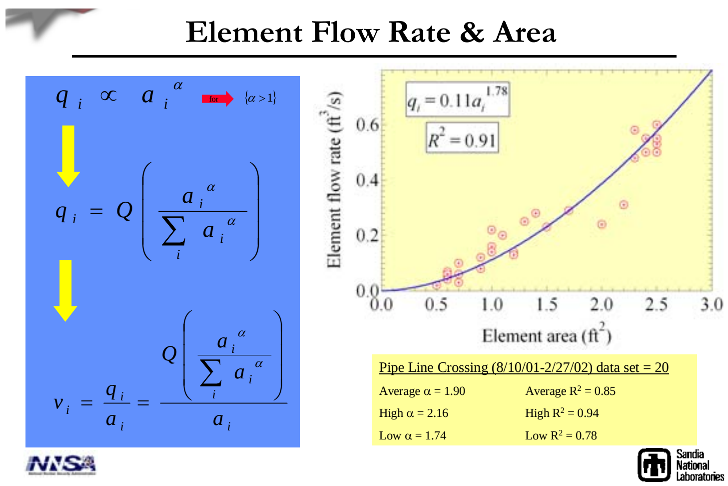
Because the Pecos River is much wider than it is deep, we chose to calculate the wetted perimeter as the wetted area divided by the mean water depth. Of course, the model can be run sequentially with an increasing reference height, thereby generating tables of wetted area, wetted perimeter, and river discharge for a suite of reference heights.



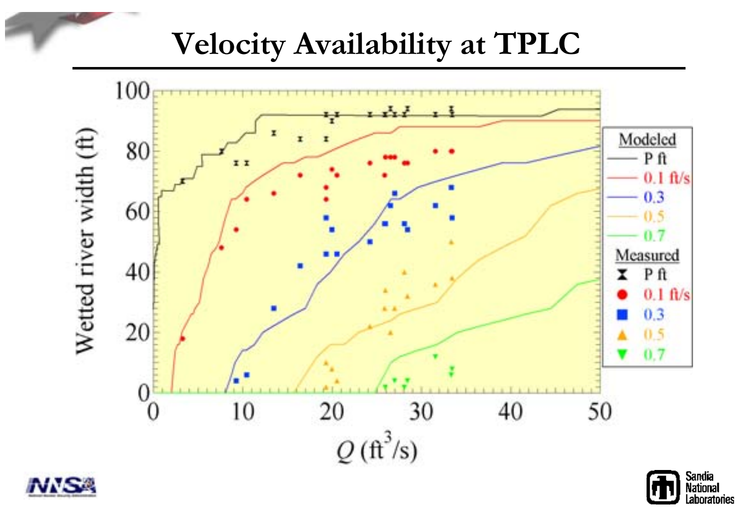
With tables of river discharge and concomitant hydraulic geometries, curves of habitat abundance can be generated by summing the length of all elements that meet some minimum habitat specification. The water depth in each element is calculated and sorted according to whether it is less than 2, 4, 6, 8, 10, or 12 in. (5.1, 10.2, 15.2, 20.3, 25.4, or 30.5 cm). Once each element has been categorized according to depth, the river width (sum of elements multiplied by their length, i.e. 2 ft) in each category is calculated for each flow rate. For example, if the total width of 2-in (5.1-cm) deep river is sought as a function of flow rate, for each sequentially higher reference height (flow rate) supplied to the model, the linear width of river 2 in. (5.1 cm) or more in depth is calculated. Ultimately, this yields a curve describing the change in 2-in. (5.1-cm) deep habitat abundance with flow rate. This process is repeated for all depth categories. The result is a series of curves that describes the width of river containing a minimum depth of 0 (or wetted perimeter), 2, 4, 6, 8, 10, and 12 in. (5.1, 10.2, 15.2, 20.3, 25.4, and 30.5 cm) as a function of river discharge. This curve can be used to select the river discharge that most appropriately fits minnow habitat criteria. Note that the field data are also displayed on the figure to support the accuracy of the model. Also, the apparent discontinuity of the model results are caused by abrupt changes in riverbed profile due to discrete measurements (an example can be seen in Figure 13). The model results contain a higher degree of a step-like appearance as the abrupt changes in riverbed profile increase in number and magnitude. (Refer to the background section of the executive summary that precedes these slides for a detailed discussion of how to use this curve.)



This graph shows the wetted river section of the ACME Gage distributed into 2-ft wide elements. Developing velocity availability curves requires knowledge of the mean river depth (known from the depth availability curves), mass conservation, and a functional relationship distributing flow within each element across a transect. Choosing the distribution of flow that best describes/predicts the conditions in the river system is the key to an accurate model. One approach is to use data from field measurements to determine the relationship between flow rate within an element and the corresponding area. This effectively captures the conditions of the natural river system and implements them in the modeling framework.



Investigation of field data showed that there was a general power law relation between the area and flow rate of an element that held true at most transects (e.g. upper right graph). The section on the left, in blue, shows how mass is conserved when distributing flow to each element by allocating the appropriate portion of the total flow to each element. The bottom left table, in yellow, shows the variability in the data its accuracy.



The model assumes that the velocity is constant across each 2 ft (0.6 m) wide element. The linear width of the channel meeting a minimum specified velocity is simply equal to the sum of the widths of the elements that demonstrate said velocity. This is repeated at sequentially increasing reference heights corresponding to different flow rates to yield velocity availability curves as a function of river discharge. Currently, the model generates wetted river width as a function of river discharge for threshold velocity values of 0.1, 0.3, 0.5, 0.7, 0.9, 1.1, 1.3, and 1.5 ft/s (3.1, 9.1, 15.2, 21.3, 27.4, 33.5, 39.6, and 45.7 cm/s). Note that the highest velocity recorded at this transect is 0.7 ft/s (21.3 cm/s). The velocity availability curves are used the same way as the depth availability curves.

Summary

- **Predicted available water depth and velocity at 11 Pecos River sites - *as a continuous function of flow rate* - and at high resolution that compared favorably to collected data.**
- **Results can be used in conjunction with preferred habitat criteria to select optimized target flows.**

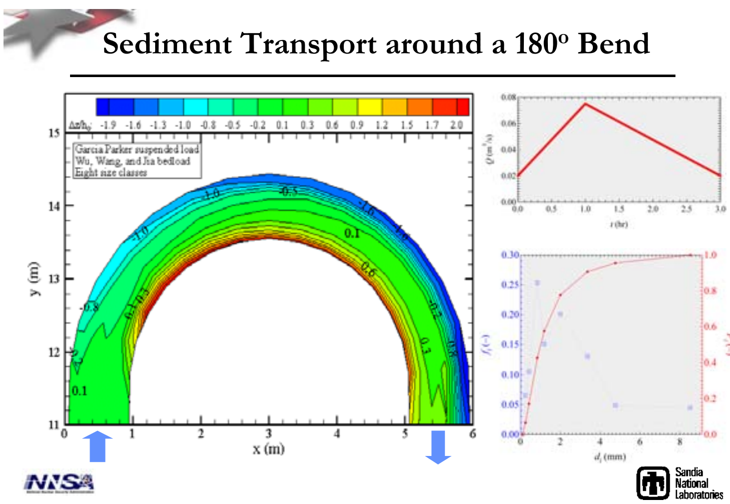
Future Work

- **Develop sediment activity availability curves**
- **Combine availability parameters**

Among the most contentious and technically difficult issues related to water resources management in New Mexico is the effect of enforcement of the Endangered Species Act for the threatened PBSM in the Pecos River. This issue has divided environmental groups, federal and state agencies, municipalities and scientific disciplines. Part of the division relates to the different management responsibilities and mandates, but a second component relates to the lack of scientific consensus concerning the habitat requirements and in-stream flow requirements for maintaining a healthy environment for the PBSM. The conflict has been exacerbated recently by the extended and extensive drought that affects the entire basin of the Pecos River. The drought has limited the management options and management flexibility enjoyed by this basin in years past.

With the recent drought conditions, the lack of water in the Pecos River Basin has provided acute and highly volatile problems for commitments to Texas, New Mexico's farmers, and wildlife. To date, neither the preferred habitat nor the minimum habitat requirements have been definitively specified. This is in part due to the general difficulty in observing PBSM preferences in the field. In the absence of this data, SNL hydrologists and engineers have developed a means to predict the available river habitat as a continuous function of river discharge through both monitoring and modeling techniques. Both the monitoring and modeling methods were performed with unprecedented horizontal spatial resolution such that available habitat is determined every 2 ft (0.6 m) across the channel. Other models considered state-of-the-art (e.g., HEC-RAS or Flow 2D) have much lower resolution for determining water depth and velocity across a transect (~10–20 ft increments) and would provide few data points across a river of this size. When the preferred and minimum habitat requirements are understood, these habitat availability curves will aid water management decisions for target river flows necessary to meet the ascribed requirements.

Once the appropriate river discharge has been decided, it will be possible, for the first time, to estimate the total yearly volume of water necessary to maintain suitable PBSM habitat over varying climatic conditions. This will likely play a critical role in the State's long-term water storage and management policies.



Environmental Fluid Dynamics Code (EFDC) incorporates hydrodynamics, salinity, temperature, dye, multi-size cohesive and non-cohesive sediments, toxicants, and water quality state variable transport into a comprehensive model. This three-dimensional model is based on a curvilinear-orthogonal grid in the horizontal, and a sigma (or stretched) transformation in the vertical. It uses a finite-volume/finite-difference formulation to ensure conservation of mass.

The large plot on the left shows EFCD results for sediment transport around a 180-deg meander bend. The contour plot shows, as expected, the inner edge is a deposition zone and the outer edge is an erosion zone. This model configuration was chosen because a detailed and well-documented set of physical experiments existed using this exact set-up. Yen and Lee (1995), hereafter referred to as YL, performed detailed measurements of bed topography and sediment sorting in a channel bend subject to unsteady flow conditions. The flow condition modeled is shown in the upper right graph and the sediment size classes modeled are shown in the lower right graph (as per YL experimental regime). Although the YL data set is not shown here the model results closely match the experimental data set.

Future work with EFDC will include the study of the evolution of a river due to bed and bank erosion including application towards endangered species and salt cedar control efforts.