Appendix C
HEC-RAS Modeling Analysis

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Estimated Velocities from Tamiami Trail Bridge Alternatives for Evaluating Alternative Performance

1. Introduction

1.1 The objective of the Tamiami Trail 2 project is to allow for "unconstrained" flows to Everglades National Park (ENP), while providing flow velocities at the bridges approaching velocities seen in the freshwater marsh. The total bridge capacity must pass the greatest anticipated flows without exceeding the maximum allowable stage in the L29 canal. For this project the Tamiami Trail will be improved to allow for a maximum stage in the L29 canal of 9.7 feet. HEC-RAS (Hydrologic Engineering Center - River Analysis System) was used to evaluate the 6 alternatives (including "no action"), plus a 10.7 mile bridge, using steady flow water surface profiles. HEC-RAS allows for simulation of multiple bridge and culvert openings by solving the one-dimensional energy equation. Energy losses were computed using a depth-varying manning's n-value, and contraction/expansion coefficients. The models show that all 6 proposed alternatives can pass the maximum anticipated flows (6,200 cfs) at the 9.7 foot design stage.

1.2 Flow rate (volume per unit time) under the bridge is estimated by multiplying the cross sectional area times the mean flow velocity (q = v*a). The cross-sectional area is a function of the total length of bridge openings. With smaller bridge openings, flow velocities and/or depths must increase to achieve the same overall flow rate. Flow under bridges is estimated using steady-state open-channel flow theory. Flow at the existing Tamiami Trail culverts is effectively open-channel flow when the culverts are not submerged. When the culverts are totally submerged during high flows, the hydraulic characteristics at the culverts are modeled as pressure flow, rather than open-channel flow. No change to the model input is required for submerged flow, or for other special cases, such as supercritical flow.

2. Analysis

2.1 The velocity (v) in the flow equation (q = v*a) for the Tamiami Trail bridges, culverts and in the marsh is a function of the manning's n-value, the cross-sectional area of flow, the wetted perimeter and water surface slope as shown below:

q (flow rate in cfs) = v*a

v (velocity in ft/sec) = $(1.5/n) \cdot R^{2/3} \cdot S^{1/2}$

R = (hydraulic radius) = a/P

a (area) = width * depth, (W*D)in ft^2, or cross-sectional area of partially filled culvert

P (wetted perimeter) = width + 2*depth, (W + 2D)in feet, or wetted perimeter of culvert

S (slope) = the gradient of the water surface profile in ft/ft

n (manning's n-value) = $A \cdot D^{b}$; Manning's n-value varies with depth (D)in feet; A & b are factors

Therefore, q = $((1.5/n) \cdot ((W \cdot D)/(W+2D))^{2/3} \cdot S^{1/2}) \cdot (W \cdot D)$

2.2 Although the marsh downstream of the culverts has a much greater cross-sectional area than the bridges, the greater roughness coefficient created by vegetation (as reflected in the manning's n-value) of the marsh results in a tailwater control on flow through the bridges. (Without bridges the existing culverts would be a control with high flows.) Depths at the bridges reflect this control, and therefore the selected n-values for the bridges have less influence over the computed water depths and flow velocities than the n-values for the marsh. The land surface elevation at the bridges and existing culverts is/will be at roughly the elevation of the existing bedrock, which is lower than the elevation of the marsh in Everglades National Park. Downstream from the existing culverts there is also an area of open/deeper water that extends for roughly 50 feet into the marsh. From this point the land surface slopes upward to the highest land surface elevations in the marsh, which are found at approximately 200 feet downstream of Tamiami Trail. Presently, in this zone the vegetation shifts from pond apple, which is less restrictive to flow, to willow and thicker marsh vegetation which is more restrictive to flow and has a higher n-value. The shallowest depth of flow is found at this location. With the bridge alternatives, generally it will be near this point of highest land surface elevation, approximately 200 feet downstream of the road, where the highest flow velocities occur.

2.3 HEC-RAS allows for a maximum of seven sets of openings (bridge and culvert sets). There are currently 19 sets of culverts, generally grouped into sets of three (55 culverts in total). To model the Tamiami Trail bridge alternatives, remaining culverts were grouped together (located together) into large culvert sets so as not to exceed the seven set maximum. As the culverts only carry a very small fraction of the total flow in all of the bridge alternatives, this simplification does not significantly affect the analysis. HEC-RAS allows for a maximum of 25 bridge spans or culverts per set. Therefore, the largest culvert sets modeled have a grouping of 25 culverts. The largest conspan bridge allowed also has a maximum of 25 spans. As a result, to achieve the desired length of conspans in some alternatives, the conspans had to be "stretched" to a larger size. Stretching conspans is a built-in feature of HEC-RAS. Again, this small modification of the conspan dimensions will not significantly alter the results of the simulations. Bridge stationing for each alternative was estimated from maps of the proposed alternatives, and the bridge lengths provided by the USACE. Culvert stationing was provided by the USGS, except where culverts were grouped into sets of more than 3 culverts. When grouped into sets of more than 3 culverts, the set was centered on a culvert that is at a representative elevation for the set, and which will not be removed by the alternative.

2.4 Existing Tamiami Trail culverts vary in diameter from 42 to 60 inches. New culverts in all alternatives are assumed to be 60 inches in diameter. The new road and bridge dimensions were taken from engineering drawings provided by the USACE, and the website for conspan bridges.

2.5 Depth at culverts and bridges is based on the average invert elevation of the existing culverts within the span of the proposed bridge or simulated culvert set.

2.6 The north-to-south land surface slope downstream of each bridge or culvert set were estimated from the SFWMM grid cell elevations and a recent survey done by the USACE for the Tamiami Trail Pilot Spreader Swales Project. The land surface slopes were checked by computing the average water surface slope at times when S333 and S334 were closed. Model results would be relatively insensitive to slope within any reasonable range of values for slope. A regression model was used to estimate marsh stages at NE2 from NE Shark Slough inflow at Tamiami Trail. Two regression models were developed: one from USGS measured flow at the Tamiami Trail culverts, and a second model developed using NE Shark Slough inflow estimated from S333 flows when S334 was closed. (NE Shark Slough inflows may be estimated from S333 flow minus S334 flow.) Both regression models gave similar results. A HEC-RAS model of an existing culvert set was used to determine values for a depth-varying n-value by calibrating to flow events of 800, 1120 and 2010 cfs. (A spreadsheet model was first used to estimate n-values. This model was "calibrated" to estimated observed depths on 4/7/1993, 3/1/2000, 8/29/2001 and 12/11/2001 and "verified" with estimated observed depths from 2/23/2000 and 12/6/2001. Average depths in the marsh were estimated from station NE2 stages. The dates were selected to represent only relatively high flow periods, but with a range of flows and depths. As described above, HEC-RAS was used to refine the selected n-values. Also, see section 2.9, below). As calibrated, the models are adequate for the intended purpose: a relative comparison of alternative performance. The models should not be used to predict actual depths. Because NE Shark Slough inflow is not the only factor determining marsh depths (for example, local rainfall), at times depths may significantly exceed those predicted by the models. When marsh depths exceed those predicted by the models, a corresponding increase in depth at the bridges will be required to pass the desired flow. Despite this, however, the models do provide assurance that the 9.7 foot stage constraint at Tamiami Trail is adequate. Table 1 shows the modeled stages in the L29 canal for example flow volumes and marsh depths.

Table 1. Example L29 Canal Stages for Modeled Flow Volume and Marsh Depth Scenarios

Alternative	Input Q Total (cfs)	Output Canal WSE	Input Marsh WSE
Alt. 1	6200	8.51	8.25
Alt. 2	6200	8.50	8.25
Alt. 4	6200	8.66	8.25
Alt. 5	6200	8.58	8.25
Alt. 6	800	7.53	7.04
Alt. 6	1120	7.64	7.11
Alt. 6	2010	7.84	7.24
Alt. 6	6200	8.45	8.25*
Alt. 6	6200	9.22	9.20**

* Predicted (typical) stage for flow of 6200 cfs

** Near maximum stage for flow of 6200 cfs

2.7 The HEC-RAS models have six transects, parallel to and between 4 feet and 3 miles downstream of Tamiami Trail. These transects define the "river station" points at which water depths and velocities are computed. The water surface slope between each station pair is also reported. The width of effective and ineffective flow at each river station, which is required input to the models, is computed from the expansion ratio at each bridge or culvert set (see section 2.8, below). The expansion ratio also defines the point downstream of the bridges at which flow has spread to the full width of the marsh.

2.8 A value for the expansion ratio (0.75) was derived from a limited calibration of the existing culvert hydraulics to observed events, and from the recommended range of values in the HEC-RAS manual. Field observations suggest that flow spreads out rapidly downstream of culverts, which is consistent with the selected expansion ratio. The same expansion ratio is assumed for the bridges. Although the expansion ratio serves to calibrate the model to observed depths, the alternative scores will not vary significantly with any reasonable value for the expansion ratio. The expansion ratio affects the computed distance to the downstream point at which the marsh depth is no longer affected by bridge/culvert hydraulics, and therefore also affects computed water surface slopes and flow velocities.

2.9 Depth and flow velocity in the marsh are based on the marsh hydraulic characteristics and land surface slope. The wetted perimeter for the marsh is the full width of the project area (10.7 miles). The initial n-value used was derived from the average values of A & b for "ridge and slough" and "ridge/sawgrass/slough" from the SFWMM documentation. The spreadsheet model was found to calibrate better when n-values vary more with depth. Both the n-value "A" factor, and the "b" factor, were increased somewhat following the limited calibration of the marsh hydraulics to observed events. The selected factors approximate SFWMM n-values at low to moderate water depths, but produce significantly lower n-values at higher water depths. Calibration with HEC-RAS resulted in n-values which vary even more with depth. Both the SFWMM and the HEC-RAS n-values are exceptionally high, except for the HEC-RAS n-values at the greatest simulated depths. Although the selected n-value served to calibrate the model to observed depths, it is important to understand that the alternative scores will not vary significantly over a broad range of n-values.

	SFWMM ridge & slough	SFWMM ridge/sawgrass/slough	HEC-RAS Model calibration
Manning's "A"	1.055	0.725	2.60
Manning's "b"	-0.77	-0.77	-2.85

2.10 The accepted target for flow capacity to NE Shark Slough is 6,200 cfs (approximately a 1 in 20 year event). This value is approximately the period-of-simulation maximum monthly NE Shark Slough (transects T18+T19) total flow volume from the Natural System Model (NSM 4.6.2). The value used is not critical to the analysis, but serves to confirm that the bridges have adequate capacity to pass unconstrained flows.

NSM T18 + T19 Max Monthly Flow	
385	kaf/mo
12833	af/day mean
6417	monthly mean cfs

3. Alternative Configurations as Modeled with HEC-RAS

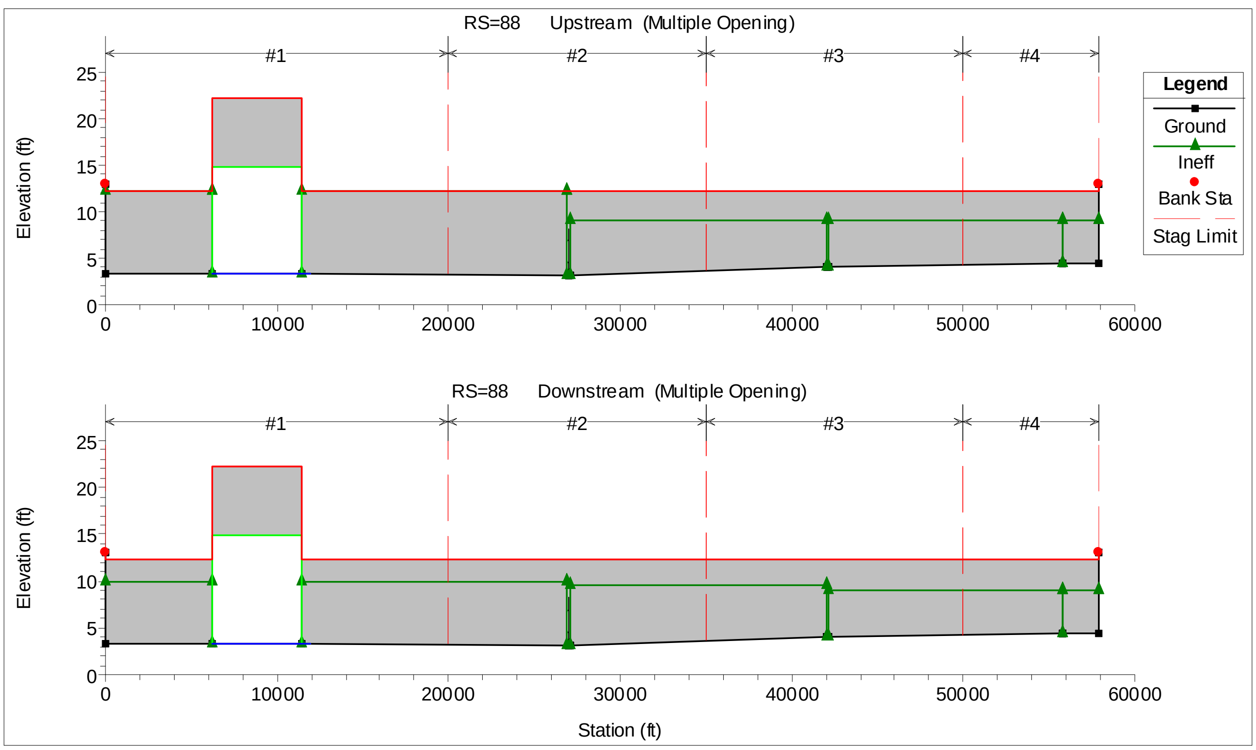

Figure 1. Base Conditions Bridge configuration at Tamiami Trail. The base condition has 1.0 mile of bridging.

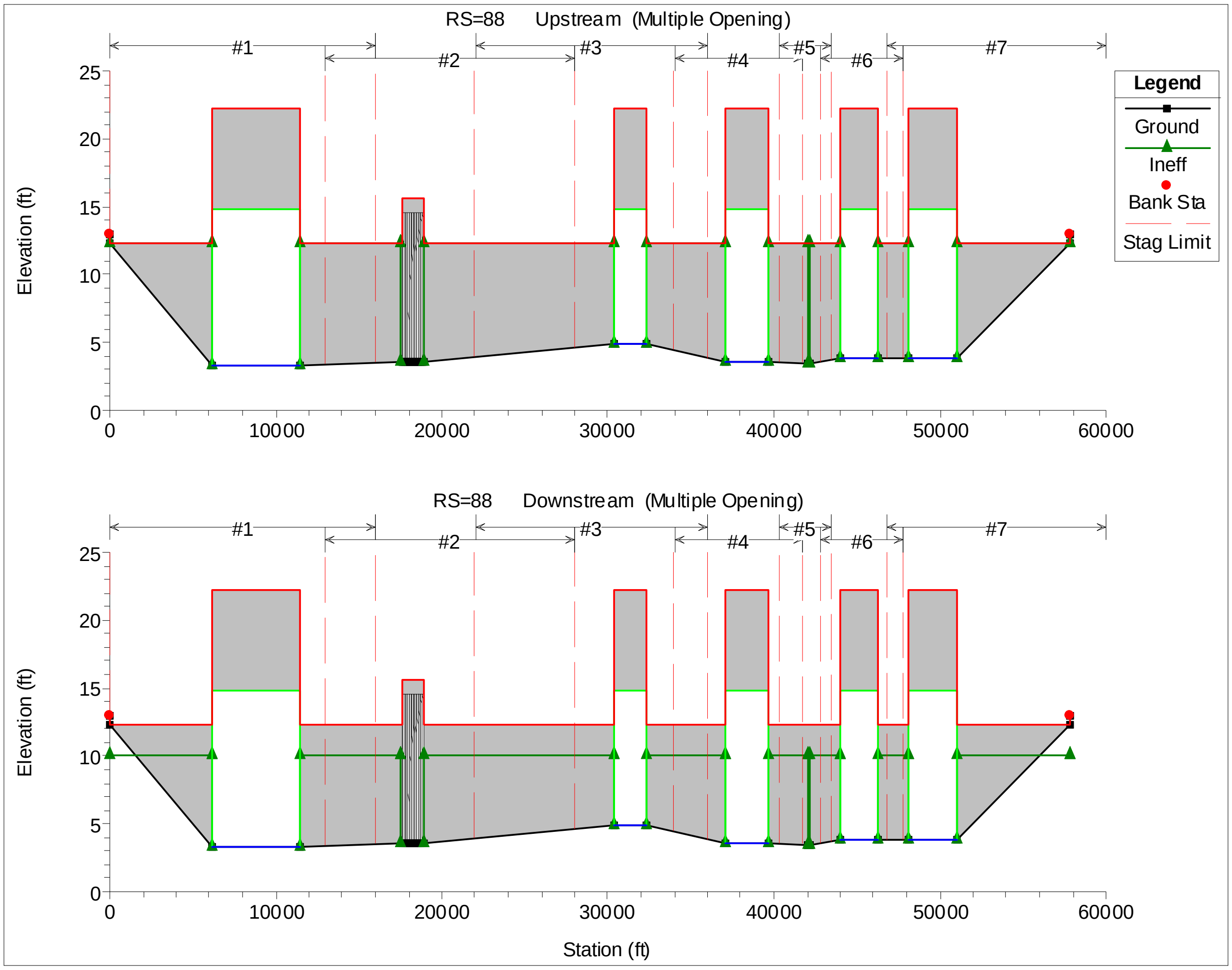

Figure 2. Alt 1 Bridge configuration at Tamiami Trail. Alt 1 has 3.15 miles of bridging in total, including a 0.26 Conspan bridge and the 1 mile bridge in the base condition.

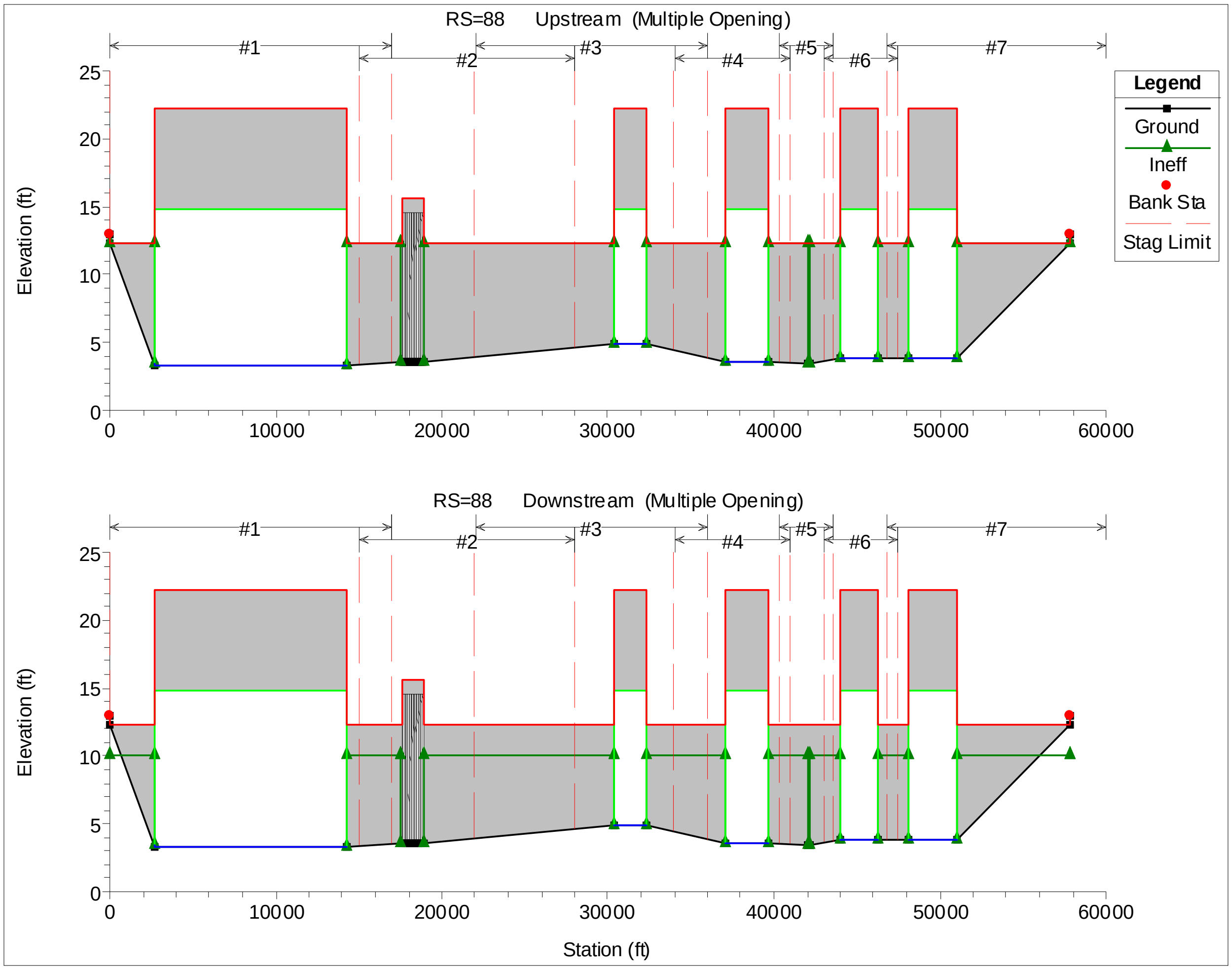

Figure 3. Alt 2 Bridge configuration at Tamiami Trail. Alt 2 has 4.34 miles of bridging in total, including a 0.26 Conspan bridge and the 1 mile bridge in the base condition. The 3 easternmost bridges are modeled as one bridge.

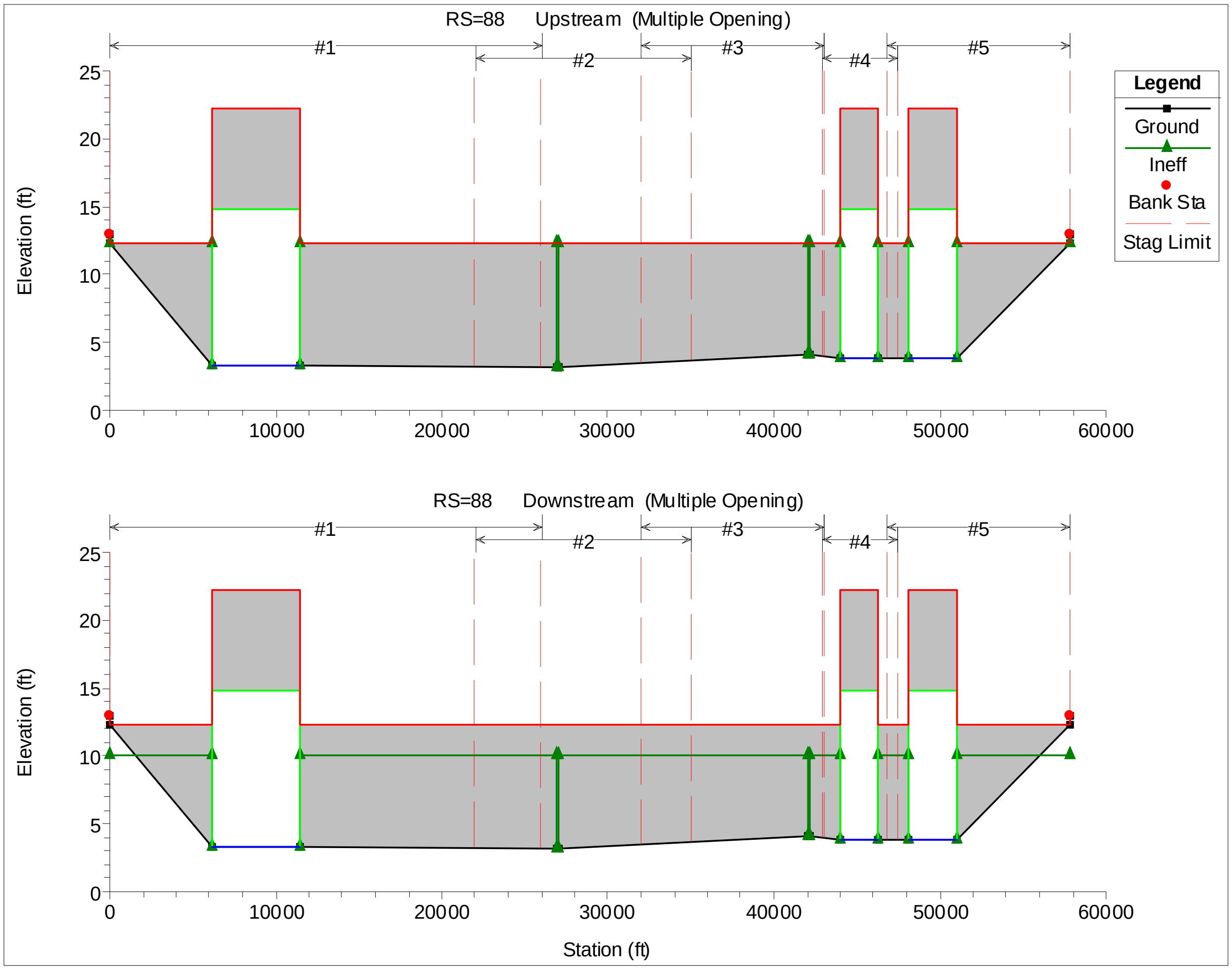

Figure 4. Alt 4 Bridge configuration at Tamiami Trail. Alt 4 has 2.01 miles of bridging in total, including the 1 mile bridge in the base condition.

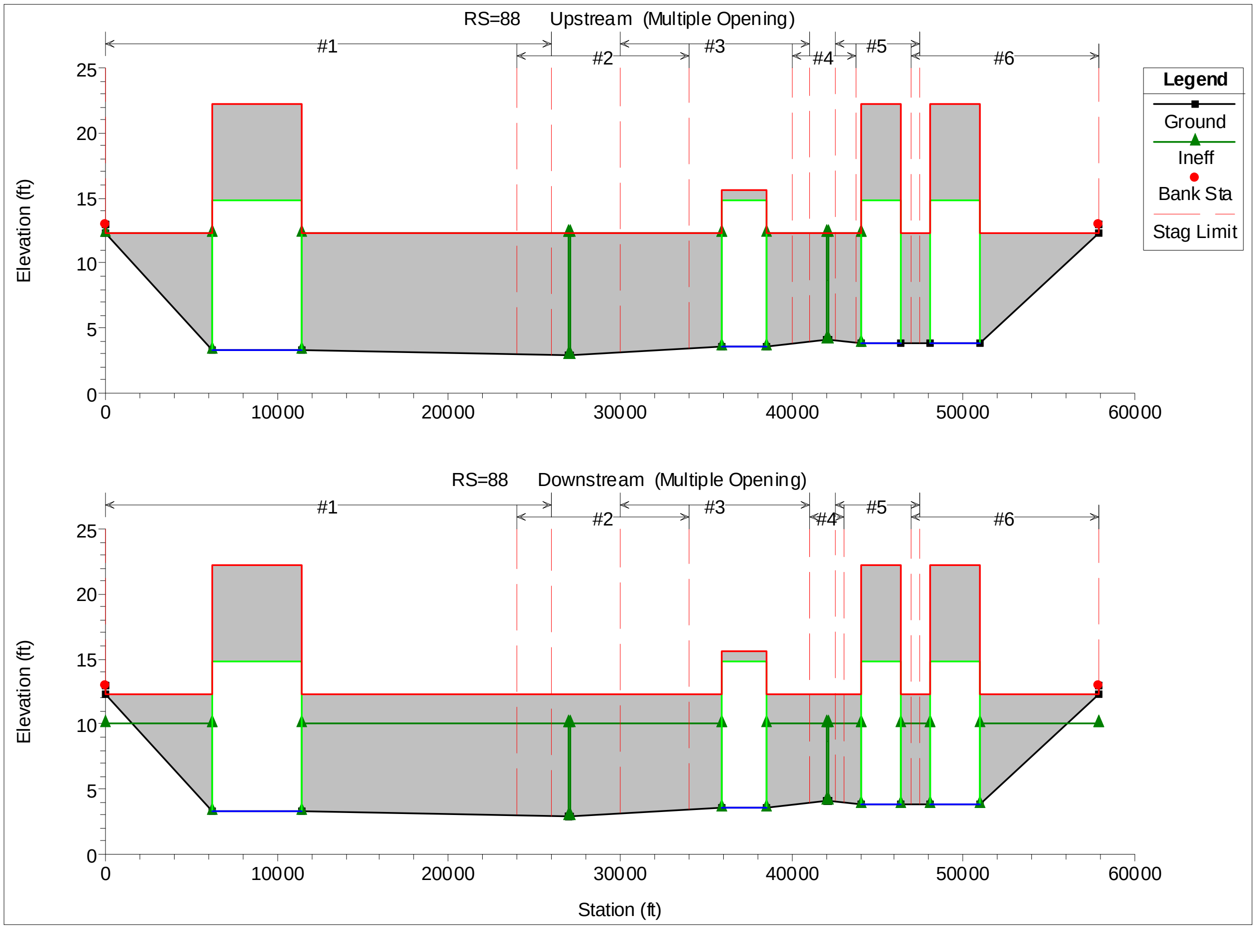

Figure 5. Alt 5 Bridge configuration at Tamiami Trail. Alt 5 has 2.52 miles of bridging in total, including the 1 mile bridge in the base condition.

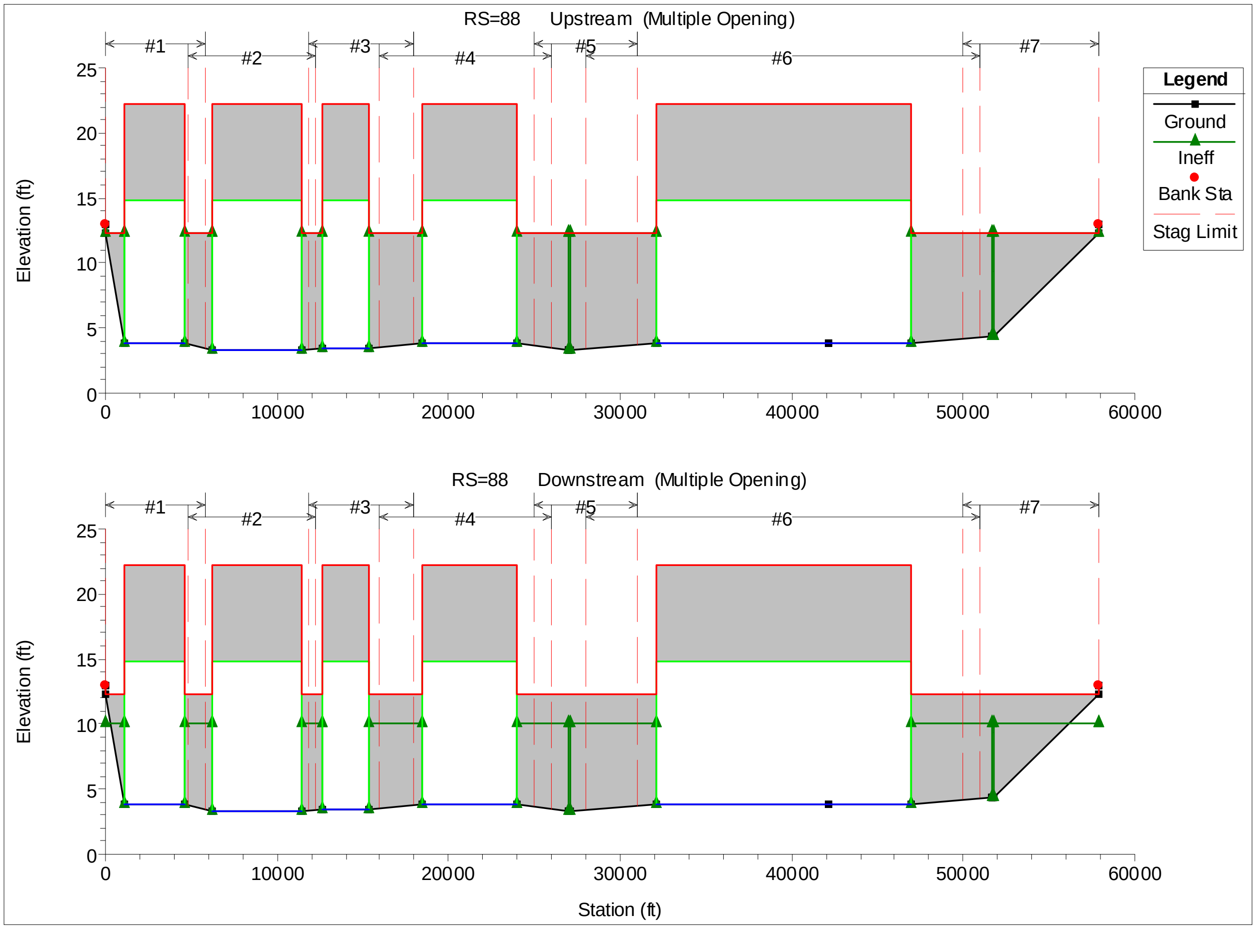

Figure 6. Alt 6 Bridge configuration at Tamiami Trail. Alt 6 has 6.05 miles of bridging in total, including the 1 mile bridge in the base condition.

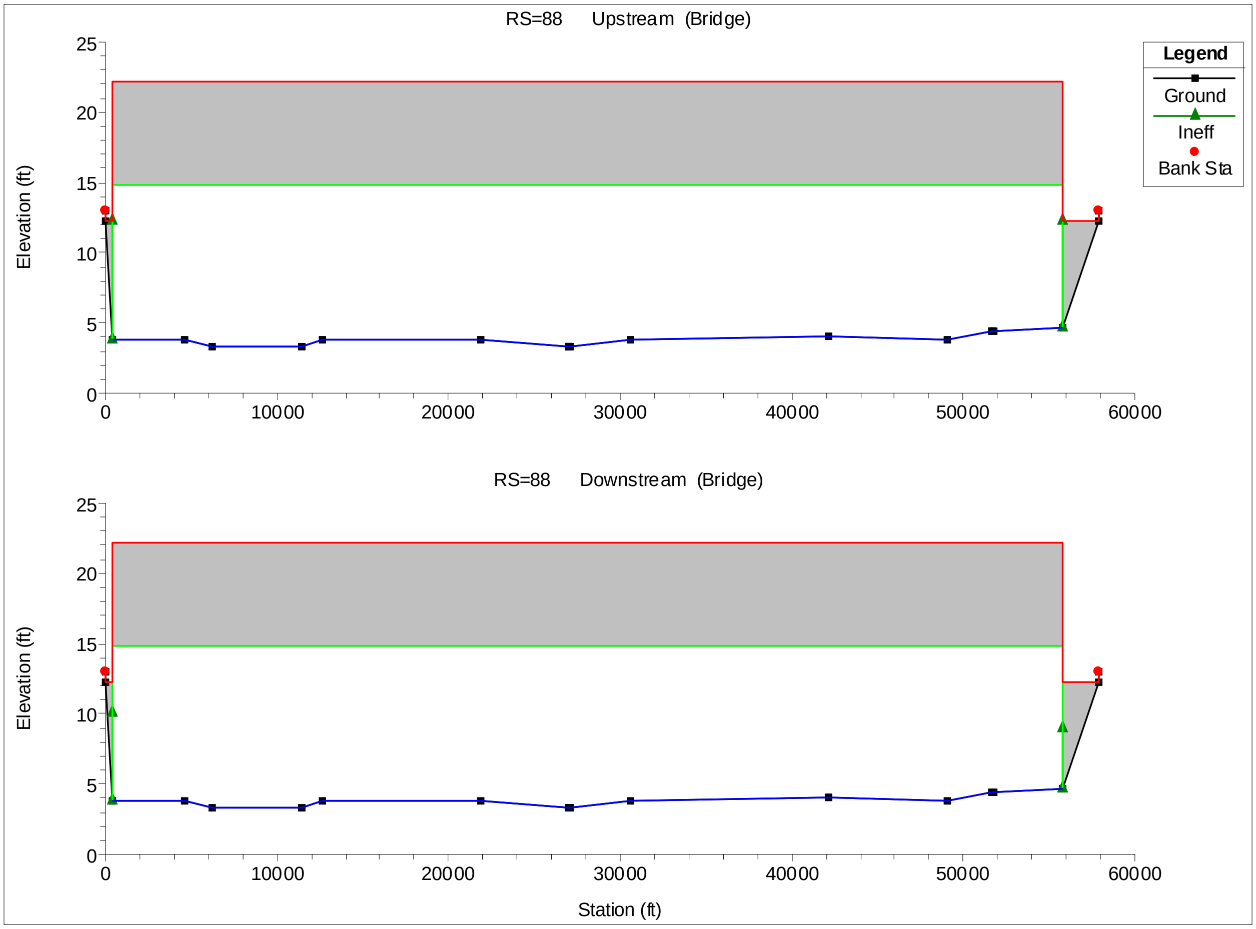

Figure 7. 10.7-mile Bridge at Tamiami Trail. Performance of alternatives is measured against flow velocities from the fully bridged model.

4. Results

4.1 Results for computed velocities at the bridges and in the marsh, and the normalized performance measure scores, are shown in the following table and graphs. The scores are for the *Difference Between Average Velocity in Marsh and Average Velocity at Road* performance measure. Performance measure scores are based on a percent increase in flow velocity at bridges over marsh velocity. Scores are normalized on a scale of 0 to 1, and represent lift above base conditions (the no-action alternative). The final graph shows the relationship between bridge length proportion of total distance and flow velocities at the bridges for the 6,200 cfs alternative scenarios.

Table 2. Tamiami Trail 2 Alternative Scores

alternative	average velocity 200' blw bridge (ft/sec)	bridge length proportion of total	increase over marsh velocity @ bridge	Normalized PM Score
No Action	0.34	9.3%	580%	0.00
Alt1	0.14	29.4%	180%	0.69
Alt2	0.10	40.6%	100%	0.83
Alt4	0.20	18.8%	300%	0.48
Alt5	0.16	23.6%	220%	0.62
Alt6	0.08	56.5%	60%	0.90
10.7-Mile Bridge	0.05	100.0%	0%	1.00

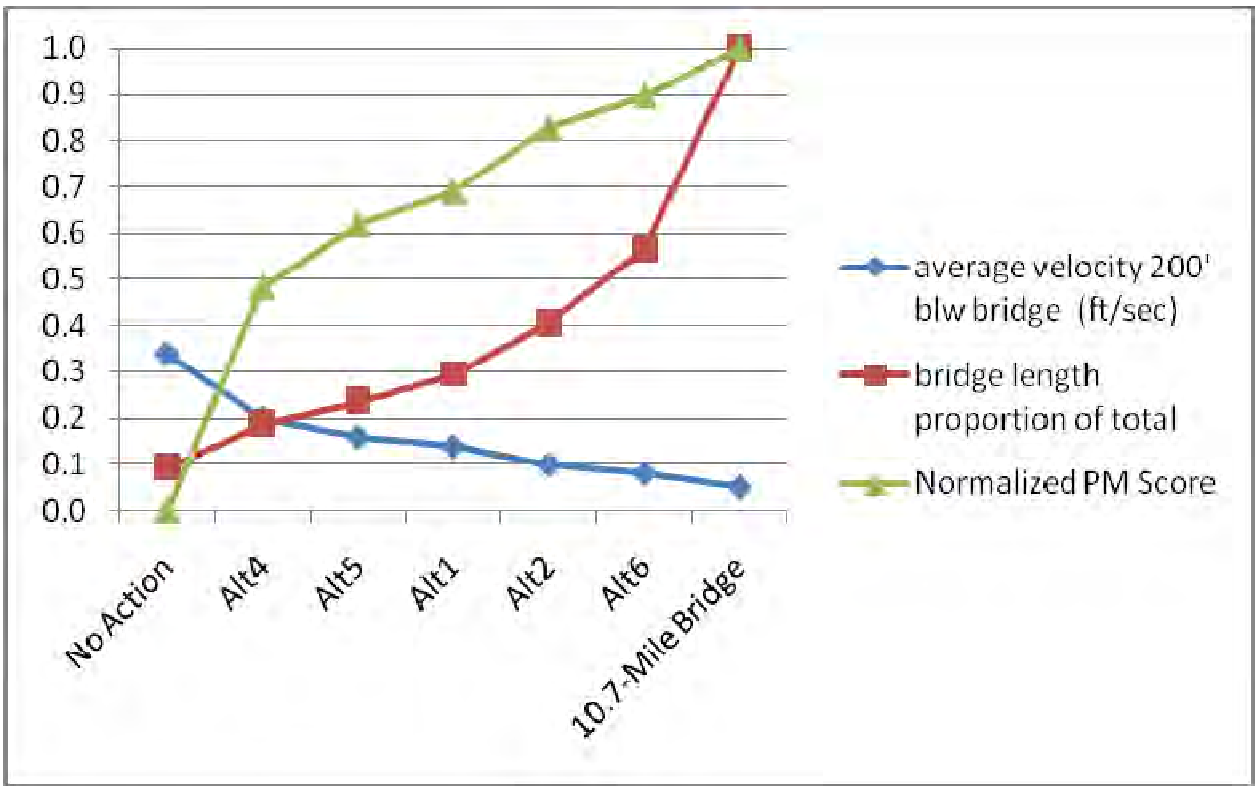

Figure 8. Average Velocity 200' downstream of bridges, Bridge length proportion of total distance and Normalized PM Scores for the Tamiami Trail 2 alternatives.

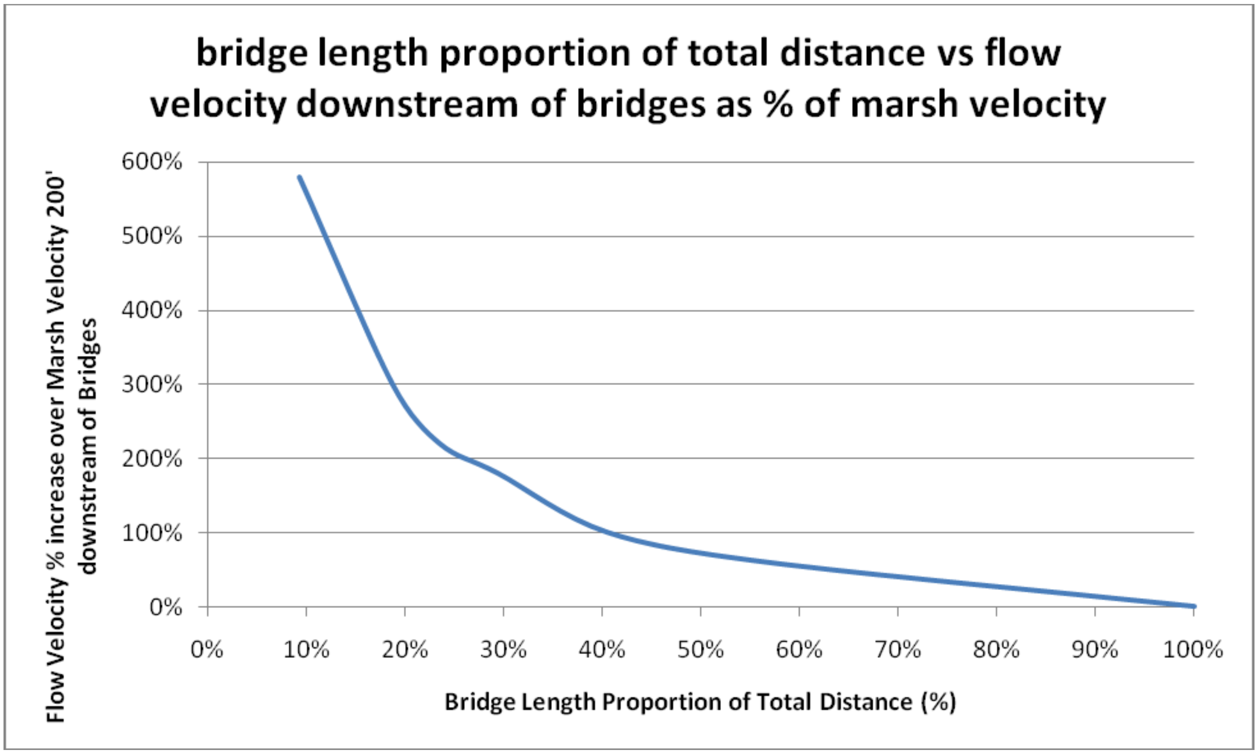

Figure 9. Bridge length proportion of total distance vs. flow velocity downstream of bridges as percent of marsh velocity for the Tamiami Trail 2 alternatives.

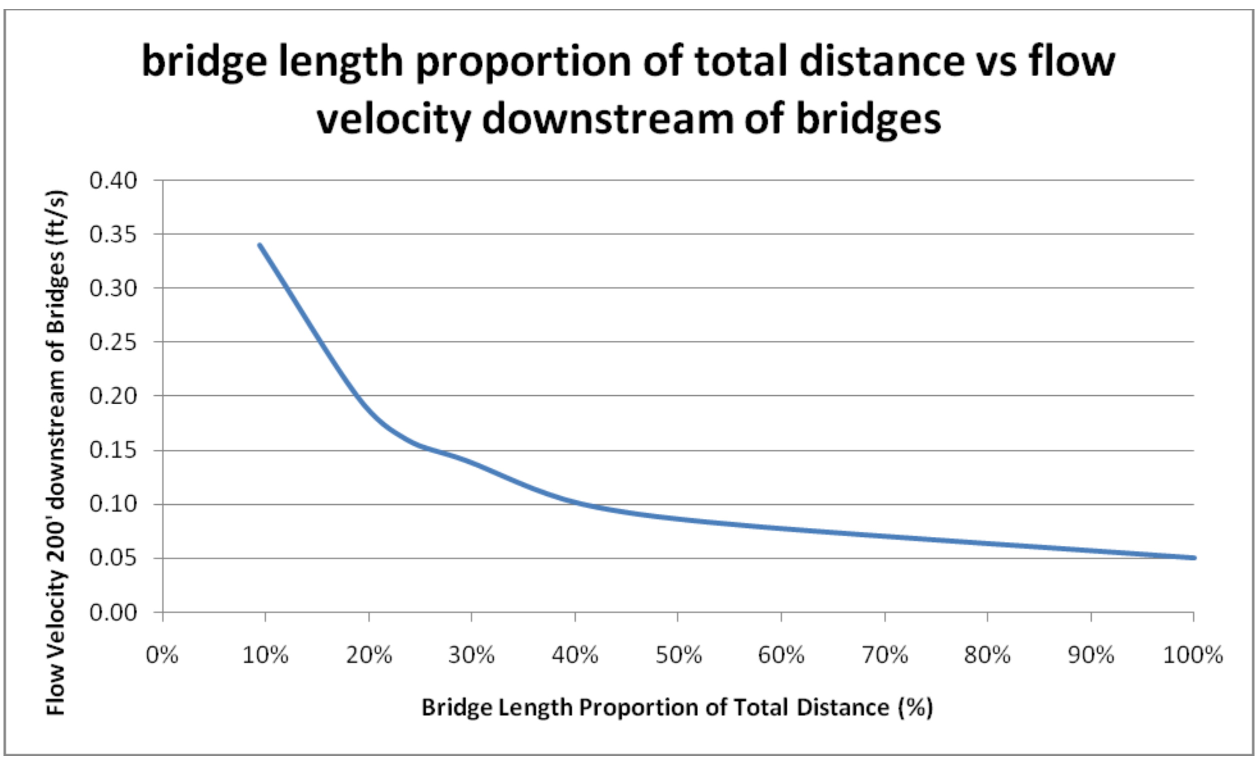

Figure 10. Bridge length proportion of total distance vs. flow velocity 200 feet downstream of bridges for the Tamiami Trail 2 alternatives.

5. Conclusions

The HEC-RAS models produce reasonable results for depth of flow and velocity. The results are adequate for the intended purpose of scoring alternative performance with the *Difference Between Average Velocity in Marsh and Average Velocity at Road* performance measure.

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