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Impacts on Heat Island Effects and Stormwater Management
Churchill Ave and Meadow-Charleston
Alternatives Comparative Analysis

City of Palo Alto

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1. Comparative Analysis

1.1 Introduction

This study is a preliminary comparative analysis between three alternatives for Churchill Avenue and four alternatives for Meadow-Charleston for construction and their impacts on heat island effects and stormwater management. In evaluating the heat island effects, consideration was given to the albedo of pavement areas and shaded areas cast by trees in vegetated areas. This study is accompanied with exhibits graphically summarizing the areas estimated for the alternatives.

1.2 Heat Island Effect

1.2.1 Introduction

Albedo plays a pivotal role in the heat absorption and retention of pavements, influencing local microclimates and heat island effects. Albedo is a measure of the ability of an object to reflect solar radiation, where values range between 0 (no sunlight reflected) to 1 (all sunlight is reflected). Generally, lighter colored materials reflect more sunlight and have higher albedo values than darker colored materials. For the purpose of this comparative analysis, assumptions and generalizations were made for pavement types and albedo values, as shown in **Table 1**.

Table 1. Albedo Values

<table>
<tr><th>Surface Type</th><th>Approximate Albedo
(assumed average)</th><th>Approximate Weathered Albedo
(assumed average)</th></tr>
<tr><td>New Roadway Pavement
(Asphalt)</td><td>0.05 – 0.10 (0.08)</td><td>0.10 – 0.15 (0.13)</td></tr>
<tr><td>New Pedestrian and Bicycle Pathway Pavement (Gray Concrete)</td><td>0.35 – 0.40 (0.38)</td><td rowspan="3">0.25 - 0.30 (0.28)</td></tr>
<tr><td>New Sidewalk
(Gray Concrete)</td><td>0.35 - 0.40 (0.38)</td></tr>
<tr><td>New Sidewalk
(White Concrete)</td><td>0.70 – 0.80 (0.75)</td></tr>
<tr><td>Vegetated Area
(Deciduous Trees)</td><td>0.15 – 0.18 (0.17)</td><td>0.15 – 0.18 (0.17)</td></tr>
</table>

1.2.2 Methodology

Pavement areas considered in this analysis include roadway pavement, sidewalk, and pedestrian pathway pavement, and railroad undercrossing pavement. Albedo values[1,2] are provided in ranges, where concrete pavement albedo values are generally higher (more sunlight reflected) when newly constructed and typically decreases with aging, and asphalt pavement albedo values are generally lower (more sunlight absorbed) when newly constructed and typically increases with aging. Pavement area estimates are summarized in **Table 2**. Roadway and sidewalk/bicycle pathway pavement surfaces were assumed to be completely comprised of asphalt and concrete, respectively. Note that the albedo of vegetated areas may also be considered, and the albedo values of trees are often higher than asphalt surfaces.

Table 2. Pavement and Vegetated Areas by Alternative

Location	Alternative	Total Roadway Pavement Area (sf)	Total Vegetated Area (sf)	Total Pedestrian and Bicycle Pathway Pavement Area (sf)	Property Acquisition (sf)	Total Vegetated Area (sf)
Churchill Ave	Underpass	101,840	24,520	33,390		24,520
	Closure with Mitigations (Option 1)	7,062	9,390	16,676		9,390
	Closure with Mitigations (Option 2)	10,992	11,820	17,266		11,820
	Viaduct					
Meadow-Charleston	Trench					
	Hybrid	129,602	8,130	22,193	20503	8,130
	Viaduct					
	Underpass	159233	3370	118740	46781	3370

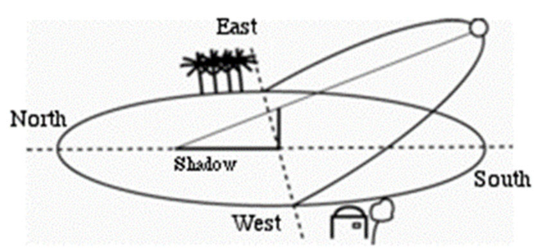
1.2.3 Evaluation Approach

The proposed improvements for the viaduct and trench alternatives are limited to the extents of the existing railroad tracks and determined to have negligible impacts on heat island effects. As a result, the viaduct and trench alternatives both Churchill Avenue and Meadow-Charleston were determined to have negligible/neutral impacts to heat island effects and not included in the evaluation.

The Churchill Avenue Underpass alternative was estimated to have a significantly larger construction area than both options of the Closure with Mitigations alternative, due to roadway grading requirements to accommodate a vehicular underpass for Churchill Avenue. Although the Underpass alternative is estimated to have a greater relative negative heat island effect due to a total pavement area of on the order of 5 to 7 times greater than the Closure with Mitigations alternative, the larger construction area of the Underpass alternative does provide additional opportunities for new vegetated areas that can provide shading from new trees and act to reduce total heat gain. If the impact of solar orientation and resultant projected shadows are considered, east-west oriented trees project longer shadows onto pavement north of the trees, as illustrated in **Figure 1**[3]. Alma Street is generally northwest-southeast oriented, so the Underpass and Closure with Mitigations (Option 1) alternatives have the largest potential to take advantage of this benefit from the solar orientation due to the larger construction areas and placement of trees along Alma Street.

Figure 1. Diagram Illustrating Longer Northward Shadows due to Solar Orientation

Trees are planted on the order of every 40 feet along the length of a vegetated area and have a 30-foot



diameter canopy. Shade from only one side of a tree was considered to provide shade onto adjacent pavement (i.e., the portion of a tree canopy furthest away from the pavement is assumed to not contribute to shading pavement areas). As shown on **Table 2**, while the Underpass alternative has the largest construction extents, it also has greater opportunities for new vegetated areas. As a result, the Underpass alternative was estimated to provide on the order of 2 to 5 times the shaded area as compared to both options of the Closure with Mitigations alternative.

Table 3. Comparison of Shaded Areas from Trees between Alternatives

Location	Alternative	Length of Vegetated Area (ft)	Number of Trees[1]	Estimated Shading over Pavement from Tree Canopies[2] (sf)
Churchill Ave	Underpass	2600	65	23000
	Closure with Mitigations (Option 1)	820	20	7100
	Closure with Mitigations (Option 2)	1707	40	14200
	Viaduct			
Meadow-Charleston	Trench	360	9	3200
	Hybrid	840	21	7,500
	Viaduct	360	9	3,200
	Underpass	2880	72	25500

Assumptions:

1 The estimated number of trees is determined by assuming a tree planted every 40 linear feet

2 Projected tree canopy is determined by assuming mature tree canopies at a 30' diameter (15' projected from the trunk)

Additional considerations in the area estimate include the property acquisitions for the Meadow-Charleston alternatives and improvements at the intersection of Alma St & Kingsley Avenue for the Churchill Closure with Mitigation alternative (both options). Note that the Meadow-Charleston property acquisitions assumed in the evaluation to be 75% concrete and 25% vegetated surface area in the proposed conditions.

1.2.4 Findings

Table 5 is a summary of total pavement areas, vegetated areas, albedo values for these surface types, and an estimate of albedo ratings and total heat island effect, between the alternatives. Also included is an existing conditions/no project baseline alternative (with an “E” suffix). The albedo rating estimate shown for each surface type is the product of the total surface area of the surface type and albedo value. Also, the total shaded area from tree canopies was considered as a credit (i.e., the shaded area is assumed to not contribute to the heat island effect). A higher Albedo Rating and Total Heat Island Effect Ratio indicates a lower heat island effect as a result of reflecting more sunlight. Therefore, the Total Heat Island Effect Rating was estimated as the sum of all albedo ratings for each surface type, with an additional positive credit applied from the total shaded area from tree canopies. The Total Heat Island Effect is a ratio of the sum of albedo ratings of the different surface types adjusted to account for shaded areas on pavement areas and sum of all surface types.

For the alternatives at Churchill Avenue, there is a clear distinction in the size of construction extents between the two alternatives. Pavement and vegetated area work is significantly higher in the Underpass alternative due to roadwork grading to accommodate a new vehicular underpass, resulting in larger estimates of new and replaced pavement and new vegetated areas. The impacts on heat island effects for each alternative may be summarized as:

- **Underpass alternative**: This alternative was estimated to have the largest overall new construction and replacement of pavement and vegetated areas, by approximately an order of 4 to 5 times larger than the next largest alternative (Closure with Mitigations). Due to the larger construction extents, this alternative provides the most potential for shading from trees onto the pavement at an estimated 23,000 sf. However, this alternative has the lowest Total Heat Island Effect Ratio, suggesting a lower and similar benefit to reducing the heat island effect per unit of impacted surface area than the Closure with Mitigations, Option 1 and Closure with Mitigations, Option 2, respectively.

- **Closure with Mitigations alternative:** Although similar, both options for this alternative may be considered to have unique advantages:
  - **Option 1 –** This option may take more advantage of solar orientation by having more trees aligned east-west, providing longer shadows from trees along Alma Street onto adjacent roadway.
  - **Option 2 –** This option provides more opportunity to plant trees in a north of Alma Street, along Churchill Avenue, while having less trees aligned east-west and benefitting to a smaller degree from solar orientations.
- **Viaduct alternative:** With improvements limited to the existing railroad tracks, this alternative is estimated to have negligible impacts on heat island effects when compared to its existing conditions.

The alternatives at Meadow-Charleston follow a similar trend, with a clear distinction in size of construction extents between the Underpass and Hybrid alternatives but with a difference in shading opportunities. The alternatives for this location are summarized in **Table 6**.

- **Underpass alternative:** This alternative was estimated to have construction extents on the order of 2 times larger than the next largest alternative (Hybrid). This Underpass alternative was also found to decrease shading canopies due to the conversion of existing vegetated areas to paved surfaces. Although having a larger construction extent and a decrease in shading, this alternative was estimated to have an approximate 20% improvement toward heat island effects when compared to its existing conditions, largely due to the construction and replacement of concrete surfaces that typically have higher albedos when newly constructed.
- **Hybrid alternative:** This alternative was estimated to have an impact on heat island effects, largely due to the replacement of existing asphalt surfaces for roadway grading and an understanding that newly constructed asphalt pavement is typically lower in albedo.
- **Trench and Viaduct alternatives:** Similar to that of the Churchill Viaduct alternative, these improvements at Meadow-Charleston are limited to the existing railroad tracks. Due to the minimal improvements and changes to land use, these two alternatives are estimated to have negligible impacts on heat island effects when compared to its existing conditions.

In general, the existing conditions/no project alternative with higher albedo values associated with weathered asphalt surface (lighter) generally have a lower heat island effect rating indicating older asphalt reflects more sunlight; whereas concrete typically darkens with age indicating new sidewalk areas with a higher albedo value reflect more sunlight than older/weathered concrete. With an understanding that surfaces with a darker albedo generally warms the surrounding climate[4], locations with very dark pavement may be understood to feel much hotter than those with light-colored surfaces.

In summary:

1. <u>**Churchill Ave alternatives:**</u>
   a. **Underpass, Closure with Mitigations, and Viaduct Alternatives Comparison:** Table 5 illustrates that the Underpass alternative performs worse than both options of the Closure with Mitigations alternative, observed through the estimated increase in Heat Island Effect (lower Heat Island Effect ratio indicating less reflecting of the sun on a per square foot basis), but noted to only perform slightly worse than Closure with Mitigations alternative, Option 2. Additionally, although significantly varying in construction extents, the Underpass alternative is estimated to have a similar minimal impact to heat island effects as the Viaduct alternative.

   b. **Closure with Mitigations Option Comparison**: Option 1 Heat Island Effect Ratio outperforms Option 2 by on the order of 40%; and,

   c. **Overall performance:** The Closure with Mitigations, Option 1 provides the overall best performance of the project alternatives for Churchill Avenue.

2. **Meadow-Charleston Ave alternatives:**

   a. Underpass, Hybrid, Viaduct, and Trench Alternatives Comparison: The Underpass alternative performs as the best alternative at Meadow-Charleston, as shown in **Table 6**, with an estimated improvement toward heat island effects when compared to existing conditions**.** The improvement is largely due to the construction and replacement of concrete pavements, increasing the overall albedo of the conditions in this alternative. On the contrary, the Hybrid alternative involves relatively significantly more asphalt pavement replacement, resulting in an overall lower albedo. Similar to Churchill Avenue, the Viaduct and Trench alternatives have minimal changes to land use and improvements due to being limited to the existing railroad tracks, so impacts to heat island effects are estimated to be negligible.

   b. **Overall performance:** The Underpass provides the overall best performance of the project alternatives for Meadow-Charleston.

1.3 Stormwater Management

1.3.1 Introduction

Generally, stormwater management involves the planning and implementation of strategies to manage and mitigate the effects of runoff generated during precipitation events (e.g., flooding, erosion, and water pollution). Runoff coefficients are parameters often used to represent the portion of precipitation that is expected to result in surface runoff, where values range between 0 (complete infiltration) and 1 (all precipitation becomes direct runoff). The value of these coefficients is influenced by various factors, including land cover, land use, and soil type. For the purposes of this comparative analysis, assumptions and generalizations were made for runoff coefficient values, as shown in Table 4.

Table 4. Runoff Coefficient Values

Surface Type	Approximate Runoff Coefficient
Roadway Pavement (Asphalt)	0.95
Pedestrian and Bicycle Pathway Pavement (Concrete)	1.00
Vegetated Area (Vegetated)	0.20
Railroad Ballast (Ballast)	0.70

1.3.2 Methodology

For each alternative, changes in overall runoff coefficients were estimated as a measure of relative increases or decreases in runoff generation, as compared to existing conditions. Changes in runoff coefficients in each alternative were estimated by calculating the approximate percent change in overall runoff coefficients between the existing and proposed conditions. Surface types in this analysis included asphalt roadway pavement, concrete pedestrian and bicycle pathway pavement, vegetated areas, and railroad ballast/gravel. Roadway and sidewalk/bicycle pathway pavement surfaces were assumed to be completely comprised of asphalt and concrete, respectively.

1.3.3 Findings

Tables 7 and 8 summarizes the estimated areas and associated runoff coefficients for each surface type and the percent change in overall runoff coefficients between the existing and proposed conditions for each alternative. Similar to the Tables 5 and 6 for the heat island effect evaluation, the existing conditions/no project baseline alternatives are labeled with an “E” suffix. Column E is the overall runoff coefficient for each alternative, calculated as the weighted average of runoff coefficients of each surface type. Column G is the estimated percent change between existing and proposed conditions, for each alternative, in Column E.

Churchill Avenue - For the alternatives at Churchill Avenue, the construction extents for the Underpass and Viaduct alternatives are distinctly larger than both options of the Closure with Mitigations alternative. Since the land areas affected for the Underpass and Viaduct alternatives are larger, the overall increase (Underpass alternative) and decrease (Viaduct alternative) in volume of runoff will also be larger. The impact on runoff generation for each alternative may be summarized as:

- **Underpass alternative:** This alternative was the only alternative estimated to have an increase (i.e., positive value in Column G of Table 7) in runoff volume generation, when compared to its existing baseline condition. This expected increase in runoff volume generation is understood to be largely due to the conversion of existing vegetation (with higher permeability) to pedestrian and bicycle pathways (with lower permeability).
- **Closure with Mitigations alternative:** The estimated percent change for both options of this alternative are similar, with both options estimated to have an expected decrease in runoff generation when compared to existing conditions. Differences between the options are mostly due to the extent of converting existing concrete and asphalt surfaces to vegetated areas.
  - **Option 1 –** This option includes the conversion of the southwest roadway asphalt pavement near the intersection of Alma St and Churchill Ave to vegetated areas, resulting in an expected decrease in runoff volume generation from existing conditions. This option also includes new pedestrian and bicycle pathway pavement along Alma St to accommodate an underpass below the railroad tracks.
  - **Option 2 –** Similar to Option 1, this option also includes the conversion of the southwest roadway at the intersection of Alma St and Churchill Ave to vegetated areas. The major difference in Option 2 and Option 1 is the configuration of the underpass for pedestrians and bicyclists. Instead, the underpass for Option 2 is designed to follow Churchill Ave and under the railroad tracks, not requiring the conversion of existing vegetated areas into new concrete and/or asphalt surfaces as shown in Option 1.
- **Viaduct alternative:** This alternative was estimated to have the largest construction extents due to the improvements following an estimated 4200-foot length of existing railroad tracks to accommodate the viaduct. With assumptions that the area under the raised viaduct will be 75% vegetated and all runoff generated on the viaduct will be captured in these vegetated areas, an overall reduction in runoff volume generation from existing conditions was estimated.

Meadow-Charleston - The alternatives at Meadow-Charleston follow similar trends as Churchill Avenue, with the Underpass and Viaduct alternatives estimated to have an increase and decrease in runoff volume generation, respectively. The alternatives at this location also include the Hybrid and Trench alternatives, with a distinctly large amount of estimated increased runoff volume generation for the Trench alternative. The impact on runoff generation for each alternative may be summarized as:

- **Trench alternative:** This alternative was estimated to have the largest expected increase in runoff volume generation. Similar to the viaduct alternative, the trench alternative follows a relatively large length of the existing railroad tracks. However, the trench alternative involves lowering the existing railroad tracks and does not provide the same opportunity to capture runoff in vegetated areas below. As a result, the estimated increase in runoff generated from converting existing railroad ballast to concrete in the trench is understood to require stormwater management.
- **Hybrid alternative:** The hybrid alternative was estimated to have a relatively minimal increase in runoff volume generation due to the proposed improvements largely involving the grading of existing roadways and having minimal changes to land use and surface types.
- **Viaduct alternative:** Following the same understanding and assumptions of the vegetated areas as the Churchill Ave Viaduct alternative, this alternative was estimated a decrease in runoff volume generation from existing conditions.
- **Underpass alternative:** This alternative was estimated to have the second largest increase in runoff volume generation when compared to existing conditions among Meadow-Charleston alternatives, greater than the next largest (i.e., Hybrid alternative) on the order of about 12 times. The Underpass alternative has the largest construction extents and involves the most improvements outside of the existing railroad tracks, among all alternatives for this location. The improvements include a relatively significant conversion of existing more permeable vegetated areas to less permeable roadway and pedestrian/bicycle pathway pavements.

In summary:

1. **Churchill Alternatives:**

   a. **Underpass, Closure with Mitigations, and Viaduct Alternatives Comparison:** Table 7 shows that, for the estimated percent change in runoff volume generation from existing conditions, the Underpass alternative performs the worst (i.e., highest positive percent change) when compared to both options of the Closure with Mitigations alternative and Viaduct alternative, in Column G.

   b. **Closure with Mitigations Option Comparison:** The percent change in runoff volume generation from existing conditions for Option 2 was estimated to perform similarly to Option 1, outperforming Option 1 on the order of 70%.

   c. **Closure with Mitigations and Viaduct Alternatives Comparison:** All alternatives and options were estimated to have a reduction in runoff volume generation when compared to existing conditions. The percent change between these alternatives and options are relatively similar, with the Closure with Mitigation (Option 2) alternative estimated to perform the best on a percent change basis, but the Viaduct alternative performing marginally better than the Closure with Mitigations (Option 1) alternative. However, a clear distinction between the two alternatives is the extent of improvements being on the order of 5 times larger and along the existing railroad tracks for the Viaduct alternative, as opposed to the smaller construction extents involving significantly more roadway improvements at the intersection of Churchill Ave for the Closure with Mitigations alternative. As a result, the Viaduct alternative is expected to have the larger overall decrease in volume of runoff from existing conditions.

   d. **Overall performance:** The Viaduct alternative was estimated to provide the best overall stormwater performance of the project alternatives for Churchill Avenue.

2. **Meadow-Charleston Alternatives:**

   a. **Underpass, Hybrid, Viaduct, and Trench Alternatives Comparison:** Table 8 shows that, for the estimated percent change in runoff volume generation from existing conditions, the Trench alternative performs the worst among the alternatives at Meadow-Charleston. The expected increase in runoff volume generation is understood to be due to increased surface imperviousness from the conversion of existing railroad ballast to concrete along the new trench. The Underpass alternative was estimated to have the next largest increase in runoff volume generation, and this estimated increased is largely due to the conversion of existing vegetated areas into pedestrian/bicycle pathways. The Hybrid alternative was estimated to have the least amount of increased runoff volume generation, since this alternative has minimal changes to land use and surface types. Lastly, the only alternative to have an estimated reduction in runoff volume generation from existing conditions, was the Viaduct alternative. An important consideration for the results of the Viaduct alternative is that the estimated percent change in runoff volume generation is largely influenced by the assumptions that the new vegetated areas under the viaduct will completely capture the runoff generated from the concrete viaduct.

   b. **Overall performance:** The Viaduct alternative was estimated to provide the best overall stormwater performance of the project alternatives for Meadow-Charleston.

Table 5. Churchill Avenue Heat Island Effect Summary

Alternative	[A]	[B]	[C]	New Pavement			[G]	[H]	[I]	[J]	[K]	[L]	[M=(J+K+L) / (A+B+C)]	[N]	[O]
	Total Roadway Pavement Area	Total Vegetated Area	Total Pedestrian and Bicycle Pathway Pavement Area	[D=A+C] Total New Pavement	[E=A/D] % Roadway	[F=C/D] % Pedestrian and Bicycle	Total Shaded Area from Tree Canopies onto Pavement	ADJUSTED Total Roadway Pavement Area =A-(E*G)	ADJUSTED Total Pedestrian and Bicycle Pathway Pavement Area =C-(F*G)	Roadway Pavement Albedo =H*0.08	Vegetated Area	New Pedestrian and Bicycle Pathway Pavement =I*0.38	Total Heat Island Effect Rating	Total Construction Extents =A+B+C	% Change from Existing Total Heat Island Effect Rating ((-) = reduction (+) = increase)
							Credit			Albedo Rating	Albedo Rating	Albedo Rating			
	(sf)	(sf)	(sf)	(sf)			(sf)	(sf)	(sf)	(Asphalt = 0.08)	(Deciduous Trees = 0.17)	(Gray Concrete = 0.38)		(sf)	
Underpass	101,840	24,520	33,390	135,230	75.3%	24.7%	23,000	84,519	27,711	6,762	4168	10,530	0.134	159,750	-2.8%
Closure with Mitigations (Option 1)	7,062	9,390	16,676	23,738	29.7%	70.3%	7,100	4,950	11,688	396	1596	4,442	0.194	28,440	22.5%
Closure with Mitigations (Option 2)	10,992	11,820	17,266	28,258	38.9%	61.1%	14,200	5,468	8,590	437	2009	3,264	0.142	35,390	17.4%
Viaduct															
										(Asphalt = 0.13)	(Deciduous Trees = 0.17)	(Gray Concrete = 0.28)			
Underpass (E)	102,764	32,690	24,296	127,060	80.9%	19.1%	23,000	84,162	19,898	10,941	5557	5,571	0.138		
Closure with Mitigations (Option 1) (E)	15,824	6,637	10,239	26,063	60.7%	39.3%	4,600	13,031	8,432	1,694	1128	2,361	0.159		
Closure with Mitigations (Option 2) (E)	24,362	4,351	8,808	33,170	73.4%	26.6%	10,700	16,503	5,967	2,145	740	1,671	0.121		
Viaduct (E)															

Table 6. Meadow-Charleston Heat Island Effect Summary

Alternative	Converted Property Acquisition (75% Ped/Bike Pavement 25% Vegetated Area)	[A] Total Roadway Pavement Area (sf)	[B] Total Vegetated Area (sf)	[C] Total Pedestrian and Bicycle Pathway Pavement Area (sf)	New Pavement [D=A+C] Total New Pavement (sf)	New Pavement [E=A/D] % Roadway	New Pavement [F=C/D] % Pedestrian and Bicycle	[G] Total Shaded Area from Tree Canopies onto Pavement Credit (sf)	[H] ADJUSTED Total Roadway Pavement Area =A-(E*G) (sf)	[I] ADJUSTED Total Pedestrian and Bicycle Pathway Pavement Area =C-(F*G) (sf)	[J] Roadway Pavement Albedo =H*0.08 Albedo Rating (Asphalt = 0.08)	[K] Vegetated Area Albedo Rating (Deciduous Trees = 0.17)	[L] New Pedestrian and Bicycle Pathway Pavement =I*0.38 Albedo Rating (Gray Concrete = 0.38)	[M=(J+K+L) / (A+B+C)] Total Heat Island Effect Rating	[N] Total Construction Extents =A+B+C (sf)	[O] % Change from Existing Total Heat Island Effect ((-) = reduction (+) = increase)
Trench																
Hybrid	20,503	129,602	8,130	22,193	151,795	85.4%	14.6%	3,200	126,870	21,725	10,150	1382	8,256	0.124	159,925	-17.8%
Viaduct																
Underpass	46,781	159,233	3,370	118,740	277,973	57.3%	42.7%	7,500	154,937	115,536	12,395	573	43,904	0.202	281,343	19.7%
											(Asphalt = 0.13)	(Deciduous Trees = 0.17)	(Gray Concrete = 0.28)			
Trench (E)																
Hybrid (E)	20,503	124,588	8,130	22,193	146,781	84.9%	15.1%	3,200	121,872	21,709	15,843	1382	6,079	0.150		
Viaduct (E)																
Underpass (E)	46,781	116,450	75,384	84,153	200,603	58.1%	41.9%	25,500	101,647	73,456	13,214	12815	20,568	0.169		

Table 7. Churchill Ave Stormwater Summary

Alternative	[A] Total Roadway Pavement Area ($C_{Asphalt}$ = 0.95) (sf)	[B] Total Vegetated Area ($C_{Vegetated}$ = 0.20) (sf)	[C] Total Pedestrian and Bicycle Pathway Pavement Area ($C_{Concrete}$ = 1.00) (sf)	[D] Railroad Ballast ($C_{Ballast}$ = 0.70) (sf)	[E] C_w $=C_{asphalt}$*([A]/[F])+ $C_{vegetated}$*([B]/[F])+ $C_{concrete}$*([C]/[F])+ $C_{ballast}$*([D]/[F])	[F] Total Construction Extents =A+B+C (sf)	[G] % Change from Existing Runoff Volumes ((-) = reduction (+) = increase)
Underpass	101,840	24,520	33,390		0.845	159,750	5.1%
Closure with Mitigations (Option 1)	7,062	9,390	16,676		0.763	33,128	-5.0%
Closure with Mitigations (Option 2)	10,992	11,820	17,266		0.750	40,078	-8.4%
Viaduct		126,000	168,000		0.657	294,000	-6.1%
Underpass (E)	102,764	32,690	24,296		0.804		
Closure with Mitigations (Option 1) (E)	15,824	6,637	10,239		0.803		
Closure with Mitigations (Option 2) (E)	24,362	4,351	8,808		0.819		
Viaduct (E)				168,000	0.700		

Table 8. Meadow-Charleston Stormwater Summary

Alternative	Converted Property Acquisition 75% Ped/Bike Pavement 25% Vegetated Area	[A] Total Roadway Pavement Area ($C_{Asphalt}$ = 0.95) (sf)	[B] Total Vegetated Area ($C_{Vegetated}$ = 0.20) (sf)	[C] Total Pedestrian and Bicycle Pathway Pavement Area ($C_{Concrete}$ = 1.00) (sf)	[D] Railroad Ballast ($C_{Ballast}$ = 0.70) (sf)	[E] C_w $=C_{asphalt}*([A]/[F])+$ $C_{vegetated}*([B]/[F])+$ $C_{concrete}*([C]/[F])+$ $C_{ballast}*([D]/[F])$	[F] Total Construction Extents =A+B+C (sf)	[G] % Change from Existing Runoff Volumes ((-) = reduction (+) = increase)
Trench				237,000		1.000	237,000	42.9%
Hybrid	**20,503**	129,602	8,130	22,193		0.919	159,925	3.4%
Viaduct			72,000	96,000		0.657	168,000	-6.1%
Underpass	**46,781**	159,233	3,370	118,740		0.962	281,343	29.0%
Trench (E)					232,000	0.700		
Hybrid (E)	**20,503**	124,588	8,130	22,193		0.889		
Viaduct (E)					100,000	0.700		
Underpass (E)	**46,781**	116,450	75,384	84,153		0.746		

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