MnDOT Flash Flood Vulnerability and Adaptation Assessment Pilot Project

DISTRICT 6 SPRING VALLEY CASE STUDY

NOVEMBER 2014

This document is part of a series of short reports based on the full Flash Flood Vulnerability and Adaptation Assessment Pilot Project.

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Federal Highway Administration

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CASE STUDY – US 63 CULVERT #5722 IN SPRING VALLEY

Introduction

This case study of Culvert #5722 was part of a larger pilot project investigating the vulnerability of assets to climate change in two of MnDOT's eight districts. The 11-step process (see sidebar at right) used to consider the impacts of climate change on a selected asset was developed by the U.S. Department of Transportation. It was originally used for the USDOT's Gulf Coast Phase 2 study[1], and was modified slightly to better fit MnDOT's needs. This process provides a framework to consider climate change at the project level.

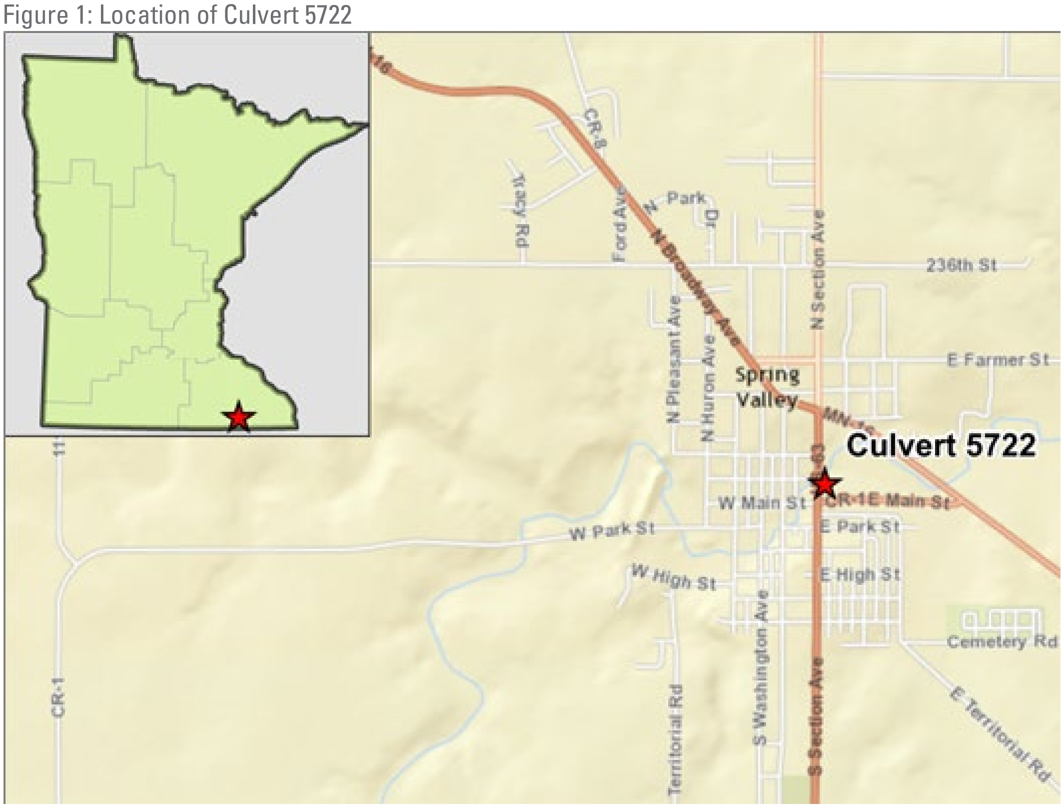
Step 1 – Describe the Site Context

Culvert 5722 carries US 63 over Spring Valley Creek and is located in the southeast portion of the state within the small town of Spring Valley (see Figure 1). US 63 is an important regional roadway linking the mid-sized cities of Rochester and Waterloo, Iowa and many rural communities in between. AADT at the facility is currently 5,700 vehicles per day and HCADT is currently 610 trucks per day.

The USDOT General Process for Transportation Facility Adaptation Assessments

1. Describe the Site Context
2. Describe the Existing/Proposed Facility
3. Identify Climate Stressors that May Impact Infrastructure Components
4. Decide on Climate Scenarios and Determine the Magnitude of Changes
5. Assess Performance of the Existing/Proposed Facility
6. Identify Adaptation Options
7. Assess Performance of the Adaptation Options
8. Conduct an Economic Analysis
9. Evaluate Additional Decision-Making Considerations
10. Select a Course of Action
11. Plan and Conduct Ongoing Activities

Figure 1: Location of Culvert 5722



1: https://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task3/task_3.2/

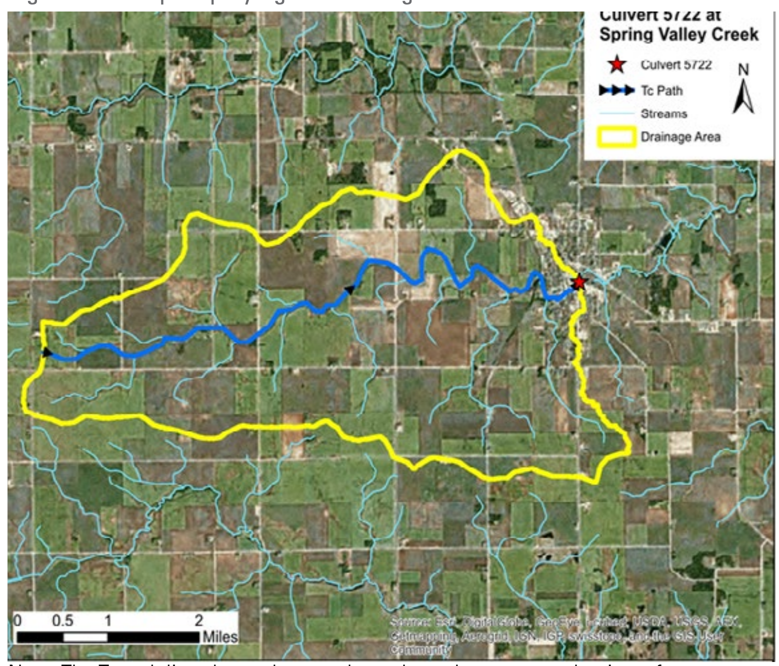
HYDROLOGIC SETTING

Spring Valley Creek is a small creek that cuts through the town of Spring Valley. Within the center of town, just upstream of the study culvert, there are numerous roadways that cross over the stream and a car dealership building cantilevered over the creek. The segment upstream (Figure 2) of the culvert is constrained by the buildings and roadways surrounding the stream. Immediately upstream of the culvert there are retaining walls extending off the culvert wing walls. The downstream area (Figure 3) is more natural and has vegetated banks with a floodplain. The total drainage area (shown in Figure 4) to the culvert is 13.93 square miles.

Figure 2: A view upstream from Culvert 5722

Figure 3: A view downstream from Culvert 5722

Figure 4: A map displaying the drainage area of Culvert 5722



Note: The Tc path line shown denotes the path used to compute the time of concentration for this facility. Time of concentration is the time needed for water to flow from the most hydrologically remote point of the drainage area to the discharge point of the area.

Step 2 – Describe the Existing Facility

Culvert 5722 is a three-cell culvert with each barrel having a 12 foot span (width) by six foot (1.8) rise (height). The barrels extend 67 feet and it is skewed 35° relative to the road as seen on the plan view in Figure 5. The culvert was originally built in 1937. The latest inspection report notes that the culvert was repaired in 1996, but describes the presence of scattered vertical cracks in the structure and spalling with exposed rebar on the culvert barrel. Figure 6 and Figure 7 are photos of the upstream and downstream ends of the culvert taken in 2014.

Step 3 – Identify Environmental Factors that may Impact Infrastructure Components

Precipitation (and the resulting stream flow) is the primary environmental factor affecting culvert design that is expected to be affected by climate change and is the focus of this study.

Step 4 – Decide on Climate Scenarios and Determine the Magnitude of Changes

It is generally believed that precipitation intensity levels will go up over time with climate change, since a warmer atmosphere is capable of holding more water vapor. Three future precipitation scenarios were considered for this adaptation assessment based on projected climate changes. The projections of future climate were developed using outputs from global climate models (GCM) that were translated to projections for the nearest weather station to Culvert 5722 using a software tool called SimCLIM. GCMs are computer models of the Earth's climate system calibrated to historic climate conditions. Future climate projections are developed by feeding plausible scenarios of future greenhouse gas emissions into the models and observing the impacts on climate variables like temperature and precipitation.

The three greenhouse gas emissions scenarios used in this study were selected to bound the range of possible future climate conditions. The scenarios pivot off the future emission trajectories, known as representative concentration pathways (RCP), that were used in the United Nations' Intergovernmental Panel on Climate Change's (IPCC) 5th Assessment Report (AR5) on climate science. The specific scenarios included:

- Low emissions scenario: RCP4.5
- Medium emissions scenario: RCP6.0
- High emissions scenario: RCP8.5

An even lower emissions scenario, RCP2.6, was considered for the analysis but the project's Climate Advisory Committee felt this scenario was highly optimistic and therefore unlikely to actually occur. Figure 8 provides a graph showing the assumed radiative forcing levels throughout the remainder of this century under the three RCPs used on this project and RCP2.6. The higher the radiative forcing values, the more warming occurs.

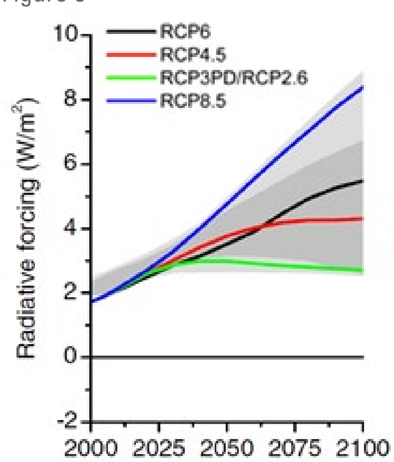
With respect to GCMs, dozens of research institutions have developed their own models, each with a slightly different take on how the Earth's climate system functions. Thus, for any given emissions scenario, each individual climate model will produce a somewhat different precipitation projection. A total of 22 GCMs were queried in this study to provide a broad perspective on the range of possible future conditions. Using the SimCLIM software tool, the range of GCM outputs

Figure 5

Figure 6

Figure 7

Figure 8



for each scenario was developed and the median output from that range used to provide the precipitation values employed in this analysis.

All three scenarios considered 24-hour precipitation depths; the storm duration most relevant to the watershed being studied and one readily generated from climate models. Storm return periods analyzed included the two-, five-, 10-, 25-, 50-, 100-, and 500-year events. Projections were obtained for three time periods through the year 2100, the anticipated end of the facility's design life.

When designing culverts using rainfall runoff models, current practice is to use precipitation frequency statistics developed from historical data by the National Oceanographic and Atmospheric Administration (NOAA) on their Atlas 14 project. It was recognized during the course of this study that, due to differences in statistical techniques, there is a discrepancy in current precipitation depths between NOAA Atlas 14 and values derived from the climate models. To correct for this bias, instead of using the raw precipitation depths directly from the climate models, the percentage change in precipitation levels between the modeled present day conditions and those in the future were recorded and those percentage changes applied to the official NOAA Atlas 14 values.

Table 1 through Table 3 show the projected precipitation levels for the drainage area of Culvert 5722 under the low, medium, and high scenarios. The current NOAA Atlas 14 value is also shown for reference in each case. The NOAA value used was derived from a frequency analysis of the annual maxima series at the centroid of the watershed. The projected data, used to the scale the NOAA values, was obtained for the Grand Meadow weather station (located approximately four miles from the culvert). The range of 24-hour precipitation values for each scenario and return period are also shown in the tables along with the percent change between observed and projected precipitation depths.

Step 5 – Assess Performance of the Existing/ Proposed Facility

Assessing the performance of a culvert first requires detailed hydrologic and hydraulic modeling of the watershed in the vicinity of the facility to understand expected peak flows. These peak flows can then be used to evaluate the culvert's performance relative to its design standards.

HYDROLOGIC MODELING

Peak flows through the culvert were modeled for various storm events and climate scenarios using the same type of WinTR-20 program used for the Silver Creek case study. As in that case study, analysis of both existing and future land cover conditions was necessary to evaluate current flows and predicted future flows at the culvert. Existing land cover conditions were obtained from the latest, 2011, National Land Cover Dataset and are shown in Figure 9.

Table 1: 24-Hour Precipitation Depths at Culvert 5722, Low Scenario

24-Hour Storm Return Period	Atlas 14 Precipitation Depth (in)[1]	Low Scenario Precipitation Depth (in)					
		2040		2070		2100	
		% Increase	Depth	% Increase	Depth	% Increase	Depth
2-year storm	2.79	3.66%	2.89	5.59%	2.95	6.50%	2.97
5-year storm	3.7	3.01%	3.81	4.61%	3.87	5.37%	3.90
10-year storm	4.49	2.89%	4.62	4.42%	4.69	5.14%	4.72
25-year storm	5.69	2.92%	5.86	4.47%	5.94	5.20%	5.99
50-year storm	6.7	3.03%	6.90	4.64%	7.01	5.40%	7.06
100-year storm	7.81	3.21%	8.06	4.91%	8.19	5.71%	8.26
500-year storm	10.8	3.76%	11.21	5.75%	11.42	6.69%	11.52

Table 2: 24-Hour Precipitation Depths at Culvert 5722, Medium Scenario

24-Hour Storm Return Period	Atlas 14 Precipitation Depth (in)[1]	Medium Scenario Precipitation Depth (in)					
		2040		2070		2100	
		% Increase	Depth	% Increase	Depth	% Increase	Depth
2-year storm	2.79	5.42%	2.94	9.00%	3.04	12.79%	3.15
5-year storm	3.7	4.47%	3.87	7.44%	3.98	10.59%	4.09
10-year storm	4.49	4.28%	4.68	7.13%	4.81	10.15%	4.95
25-year storm	5.69	4.33%	5.94	7.20%	6.10	10.26%	6.27
50-year storm	6.7	4.50%	7.00	7.49%	7.20	10.66%	7.41
100-year storm	7.81	4.76%	8.18	7.91%	8.43	11.26%	8.69
500-year storm	10.8	5.58%	11.40	9.28%	11.80	13.23%	12.23

Table 3: 24-Hour Precipitation Depths at Culvert 5722, High Scenario

24-Hour Storm Return Period	Atlas 14 Precipitation Depth (in)[1]	High Scenario Precipitation Depth (in)					
		2040		2070		2100	
		% Increase	Depth	% Increase	Depth	% Increase	Depth
2-year storm	2.79	10.08%	3.07	20.44%	3.36	30.48%	3.64
5-year storm	3.7	8.33%	4.01	16.99%	4.33	25.42%	4.64
10-year storm	4.49	7.98%	4.85	16.30%	5.22	24.40%	5.59
25-year storm	5.69	8.07%	6.15	16.46%	6.63	24.64%	7.09
50-year storm	6.7	8.39%	7.26	17.11%	7.85	25.61%	8.42
100-year storm	7.81	8.86%	8.50	18.08%	9.22	27.07%	9.92
500-year storm	10.8	10.40%	11.92	21.26%	13.10	31.94%	14.25

Derivation of future land cover involved developing a build out of zoned land uses within the drainage area. This involved consulting the zoning ordinances for the three jurisdictions with zoning authority in the drainage area: Mower County, Fillmore County, and the town of Spring Valley. In the Mower and Fillmore County portions of the drainage area, the zoning is agricultural, so existing land cover was assumed to remain in place for the future. Within the town of Spring Valley, there remains some vacant land zoned for development; these areas were assumed to be built out in the future land cover projections. Overall, the existing land cover resulted in a curve number value of 80. Future land use had an increase of 0.5 but, using the whole number rounding convention traditionally employed when reporting curve numbers, the value remained 80.

Figure 9: Land cover in the watershed leading to Culvert 5722

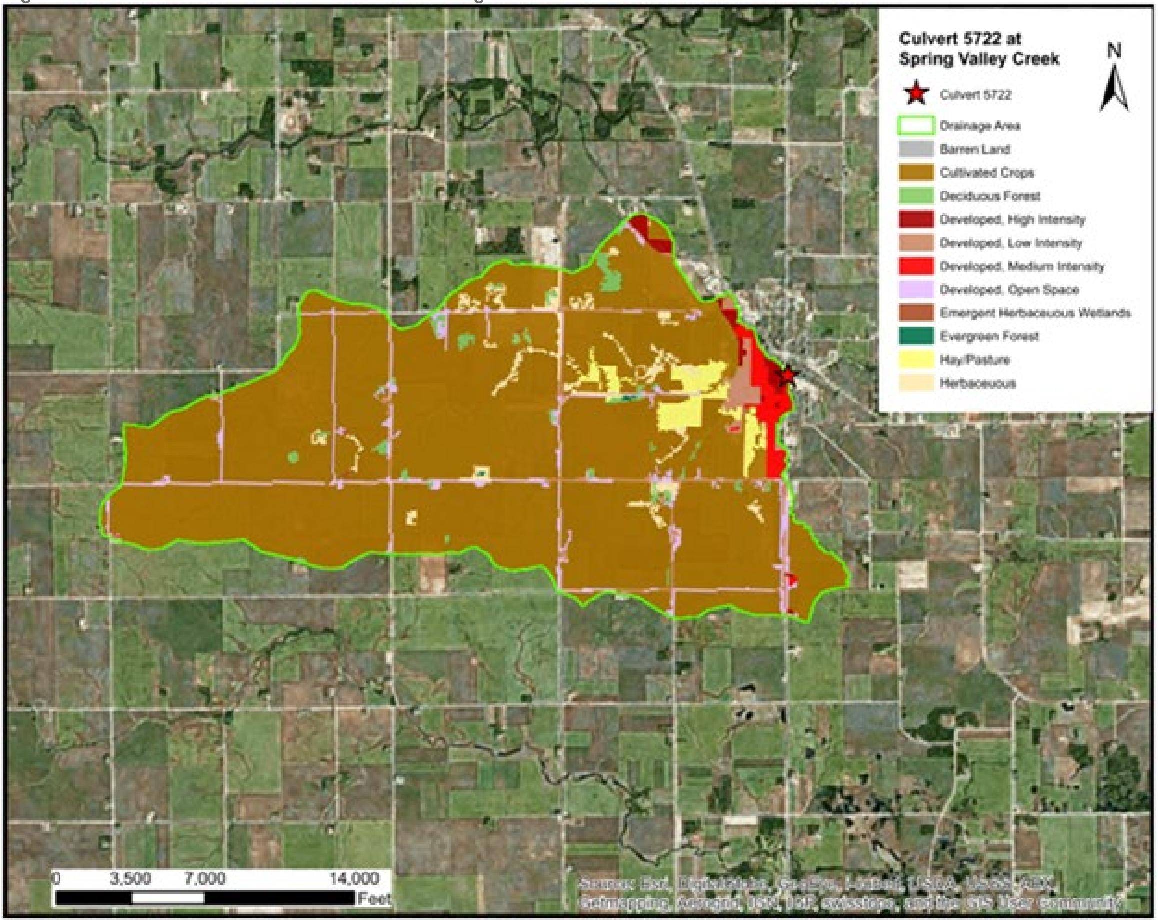


Table 4: TR-20 Projected Peak Flows at Culvert 5722

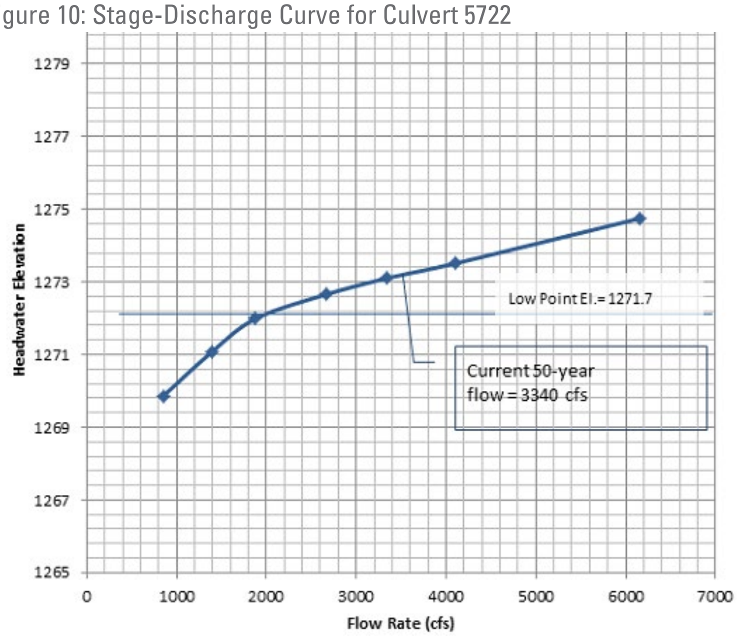
24-Hour Storm Return Period	Existing Discharges (cfs)	Low Scenario Discharges			Medium Scenario Discharges			High Scenario Discharges		
		2040 (cfs)	2070 (cfs)	2100 (cfs)	2040 (cfs)	2070 (cfs)	2100 (cfs)	2040 (cfs)	2070 (cfs)	2100 (cfs)
2-year storm	850	930	965	980	960	1020	1080	1040	1210	1380
5-year storm	1390	1480	1520	1540	1520	1590	1660	1610	1810	2010
10-year storm	1880	2000	2040	2060	2030	2120	2210	2150	2390	2630
25-year storm	2670	2810	2860	2890	2860	2970	3090	3000	3330	3650
50-year storm	3340	3520	3590	3630	3590	3720	3870	3760	4170	4550
100-year storm	4100	4310	4400	4445	4390	4560	4740	4610	5100	5590
500-year storm	6160	6490	6630	6700	6620	6900	7200	6980	7800	8600

A time of concentration value of 10.4 hours was used for existing and future condition models. Table 4 shows the model outputs comparing current peak flows to projected future peak flows at Culvert 5722.

HYDRAULIC MODELING AND PERFORMANCE OF THE EXISTING CULVERT

Hydraulic culvert analyses were conducted to evaluate the performance of Culvert 5722 under current and future peak flows. The existing facility was analyzed as the base case in this study since no improvements are currently planned for the asset. An existing HEC-RAS hydraulic model, developed for the Federal Emergency Management Agency's Spring Valley Flood Insurance Study, was modified to accommodate existing conditions. The main modification in the model was the replacement of the bridge downstream of Culvert 5722. A smaller bridge existed at the time the model was developed. The peak flows developed through the hydrologic analysis were analyzed with the culvert model to determine the headwater elevation at the culvert for various climate scenarios. The stage-discharge curve shown in Figure 10 demonstrates that the MnDOT design criterion for culverts (that a 50-year storm should be passable with 3 feet of freeboard) is not met. Even under current climate conditions, the culvert is overtopped by storms much weaker than the 50-year design storm.

Figure 10: Stage-Discharge Curve for Culvert 5722



Note: Headwater elevation is the level of water immediately upstream of the inlet (upstream end) of a culvert or any other conduit.

Step 6 – Develop Adaptive Design Options

Since the existing structure does not meet design criteria for current and future conditions, a series of three adaption options were developed for the crossing. The adaptation options take into consideration the different climate scenarios discussed in Step 5. When considering the costs of the adaptation options cited below, note that the existing culvert is estimated to cost $460,000 to replace.

OPTION ONE

Option One adds two additional 12 foot span (width) by six foot rise (height) cells to the existing culvert design. Figure 11 shows an aerial view of this design option. Figure 12 shows cross-sections of this design option.

Figure 11

The work as estimated includes:

- Traffic control
- Riprap for the outfall scour pool
- Erosion control and stream diversion
- Demolition , excavation, and structural backfill
- New culvert cells and culvert end section
- Pavement restoration

The estimated project cost is $690,000.

Figure 12: Cross-Sections of Design Option 1 for Culvert 5722

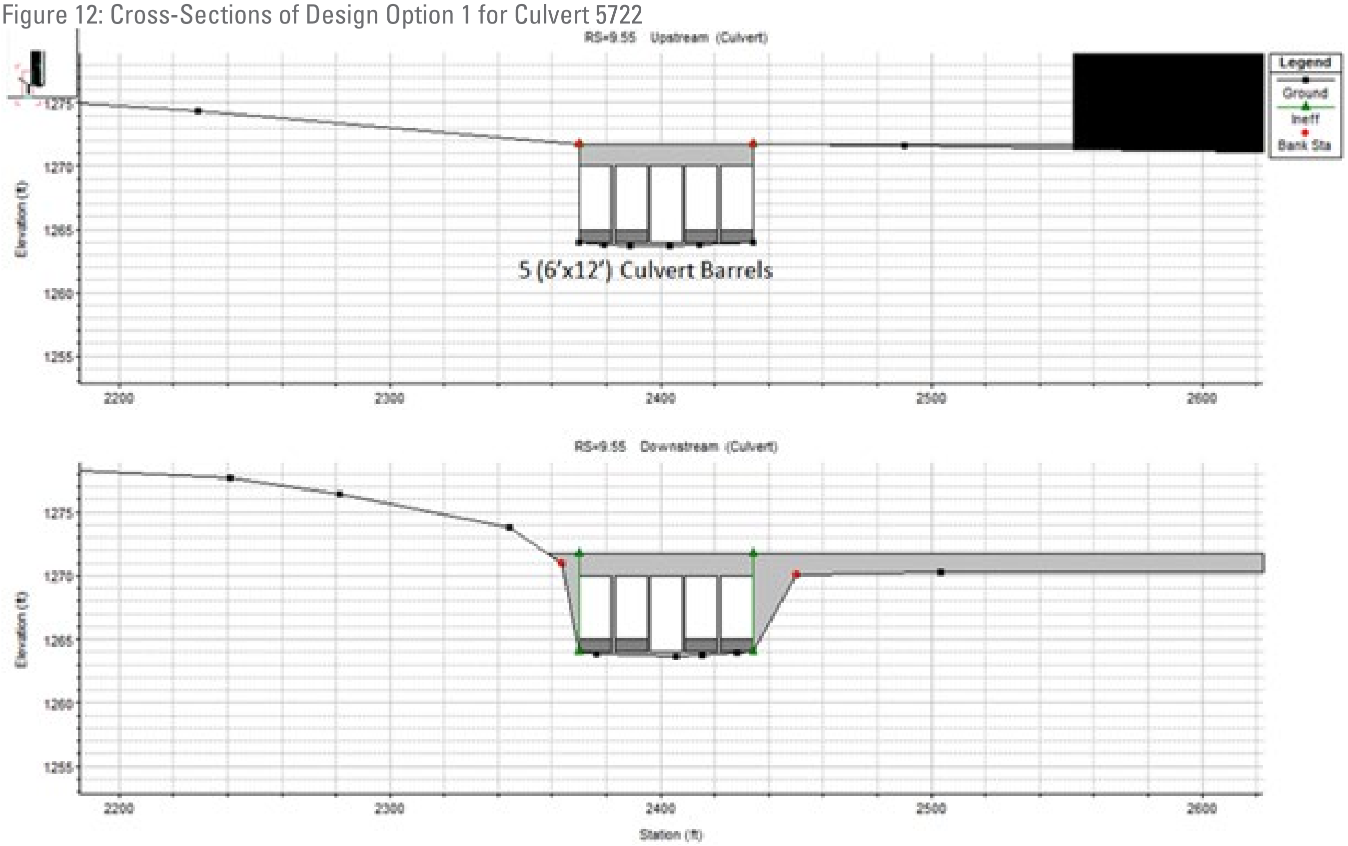
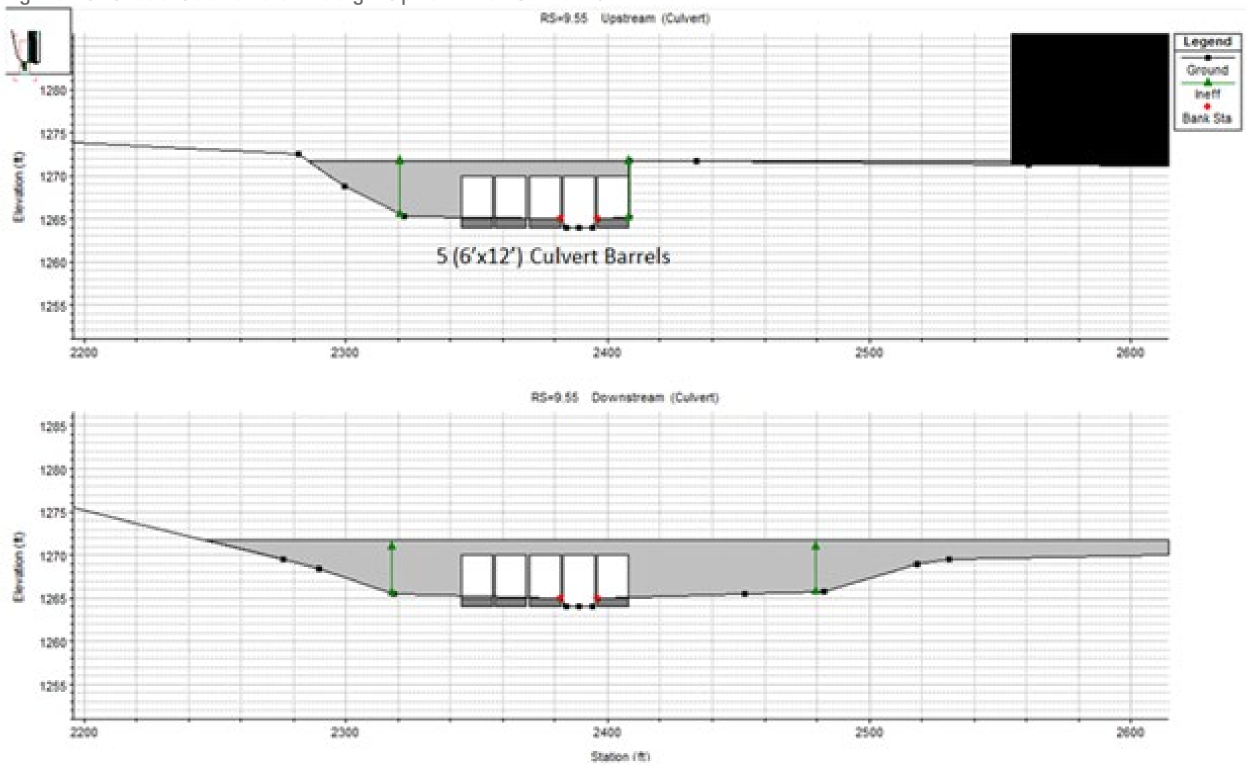


Figure 13: Cross-Sections of Design Option 2 for Culvert 5722



OPTION TWO

Option Two includes the same structural changes as in Option One, but adds floodplain enhancement upstream to allow the river to spread out, lowering peak flow elevations. The work as estimated includes all items mentioned above for Option One and the additional costs of the floodplain enhancements (including property acquisition and the demolition of one structure). The total estimated project cost is $1,640,000. Figure 13 shows cross-sections of this design option.

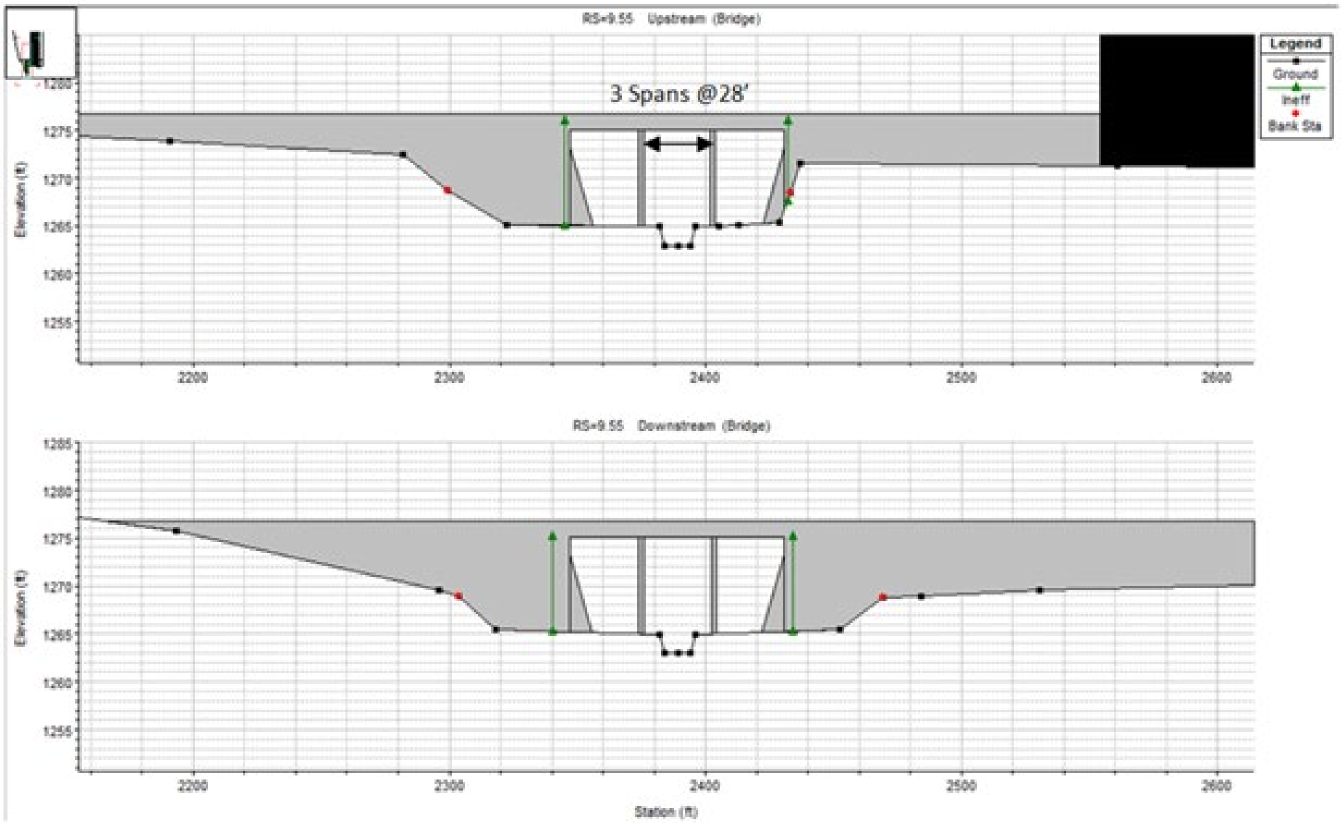
OPTION THREE

Option three replaces the existing culvert with a three span bridge. Each span is 28 feet in length. This option was designed to meet MnDOT design criteria for the 50-year storm in 2100. The bridge would have abutments with a one percent slope on both sides and two piers. The lowest deck elevation is 1,275.1 feet and the highest point is 1,276.8 feet. The roadway will need to be raised approximately five feet either side of the bridge. This work will necessitate the closing and/or re-design of some intersections with local streets. Figure 14 shows cross-sections of this design option.The work as estimated includes:

- Traffic control
- Riprap for abutment protection
- Erosion control and stream diversion
- Demolition , excavation, and structural backfill
- A new 28 foot multi-span bridge
- Associated road elevating and retaining wall construction

The estimated project cost is $4,210,000.

Figure 14: Cross-Sections of Design Option 3 for Culvert 5722



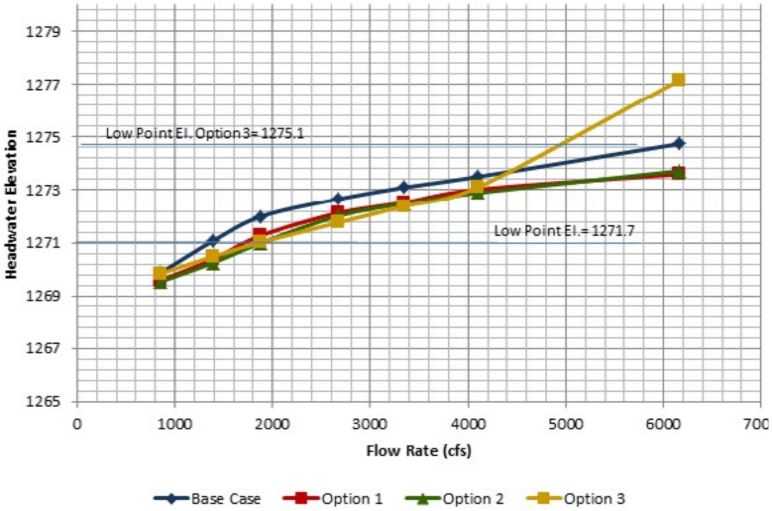
Step 7 – Assess Performance of the Adaptive Design Options

The degree of flooding was analyzed for each adaptive design option using the 50-year storm event for all three scenarios. Figure 15 presents the stage-discharge curves for the different adaptation options. Although an improvement over the existing culvert, Option 1 and Option 2 do not meet the MnDOT design criteria—overtopping during even the present day 50-year storm. Option 3, on the other hand, does not overtop under the 50-year storm even under the high climate change scenario in 2100. That said, there is some erosion in the three foot freeboard requirement under this set of conditions but this could be acceptable in this context.

Step 8 – Conduct an Economic Analysis

The consultant team performed an economic analysis for the Spring Valley Creek crossing using the COAST tool. The COAST software is designed to calculate expected cumulative damages to transportation facilities over time, using curves relating water depths to their probabilities and water depths to damage costs incurred (depth-damage functions). Water levels at the facility are assessed using the heights and probabilities (return periods) provided in the depth-probability tables shown above. Every time the facility is flooded, damage is calculated according to the depth-damage function and summed for all such events over time. Each design option has its own depth-damage function.

Figure 15: Stage-Discharge Curves for Culvert 5722 Adaptation Options



Since no improvements at Spring Valley are currently programmed, it was assumed that any adaptation options would not be completed until 2025. One other important item of note is that, for the purposes of the study, it was assumed that the base case existing asset would be replaced in kind in the year 2037 when the existing facility reaches the end of its design life. In all cases, the analyses were run until the year 2100 when it is expected that the design life of the adaptation options will be drawing to a close. As at Silver Creek, a total of 72 model runs were performed; 36 with social costs included and 36 without.

Damage costs accounted for the depth-damage functions include:

- Physical damage repair costs: Estimates of the cost to repair each adaptation option given various levels of damage. These costs include the costs for parts and labor along with contingency and mobilization factors.
- Incremental travel time costs to motorists from the detour: Time is valuable and there is a cost imposed on motorists when a trip takes longer because of the need to detour a damaged facility. An estimate of the costs of lost time for detouring Culvert 5722 was developed by considering the additional 1.5 minutes of travel time required to take the detour route (shown in Figure 16) then comparing this with traffic volumes and MnDOT recommended travel time values for motorists and freight. In addition, there is also an increase in vehicle operating costs (fuel, wear and tear, etc.) due to the 0.6 additional miles required to detour the facility. This cost was computed using MnDOT recommended operating costs and added to the travel time costs to arrive at a total estimated detour cost of approximately $140,000 per day. The length of time the detour is likely to be in place for various levels of damage was also accounted for and used to multiply the daily detour cost to arrive at a total detour cost per flooding incident. The maximum number of days a detour would be required was assumed to be 15 days for each option.
- The potential for injury to motorists: When a culvert fails, there is a possibility for accidents and associated injuries. An estimated cost of injury

Detour Cost Assumptions

Parameters	Spring Valley
Increase in Length	0.6 miles
Increase in Travel Time	0.025 hours
AADT	5,700 vehicles / day
Passenger Cars	5,090 cars / day
Trucks	610 trucks / day
VOT	1.3 MnDOT
Person Trips	6,617
Truck Trips	610
Value of Passenger Travel Time	$16 / hour
Value of Truck Travel Time	$27.3 / hour
Car Operating Cost	$0.31 / mile
Truck Operating Cost	$0.96 / mile

Detour Cost Per Day

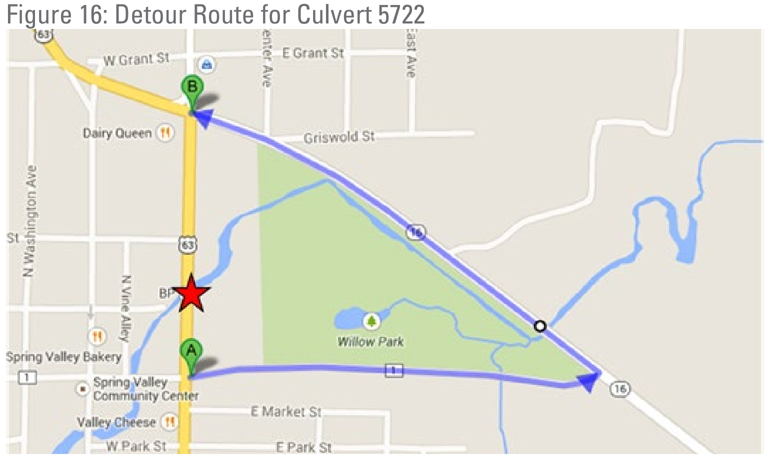
	Truck	Car	Total
Operating Costs	$351	$947	$1,298
Time Costs	$416	$2,647	$3,063
Total	$768	$3,594	$4,361

of $80,000 per flood event was included to reflect this possibility. The value chosen was approximately the same as the MnDOT recommended costs for a crash with moderate injuries (Type C). This value was selected to balance the likelihood that no accident will occur with the unlikely (but still possible) chance of an accident with fatalities.However, at approximately $4,000 per day, the detour costs were much lower than with Culvert 5648 because, as shown in Figure 16, the detour route was much shorter (0.6 miles) and added only 1.5 minutes of travel time. The maximum duration of the detour was assumed to be 15 days for the base case, Option 1, and Option 2. However, for Option 3, the maximum duration of the detour was assumed to be 60 days to reflect the possibility of foundation failure of the bridge and the long time that would be required to repair such damage. Figure 17 presents the depth-damage functions for each design option with social costs considered and Figure 18 presents the depth-damage functions excluding those costs.

Results of the analysis comparing the expected total life cycle costs (including construction) can be found in Table 6 through Table 11. Figure 19 and Figure 20 display this information graphically.

The key conclusion of the analysis is that, whether or not social costs of detours and injuries are included, Option 1, the expanded five cell culvert, is the most cost effective design in all rainfall increase scenarios (low, medium, and high). Thus, Option 1 would be the preferred option under the range of climate scenarios tested. That said, although the economic analysis identifies the most cost-effective option, decision-makers should consider other social or political criteria not included in the modeling before deciding on a course of action.

Figure 16: Detour Route for Culvert 5722



Source of background image: Google Maps

Figure 17: Depth-Damage Functions for the Culvert 5722 Design Options With Social Costs

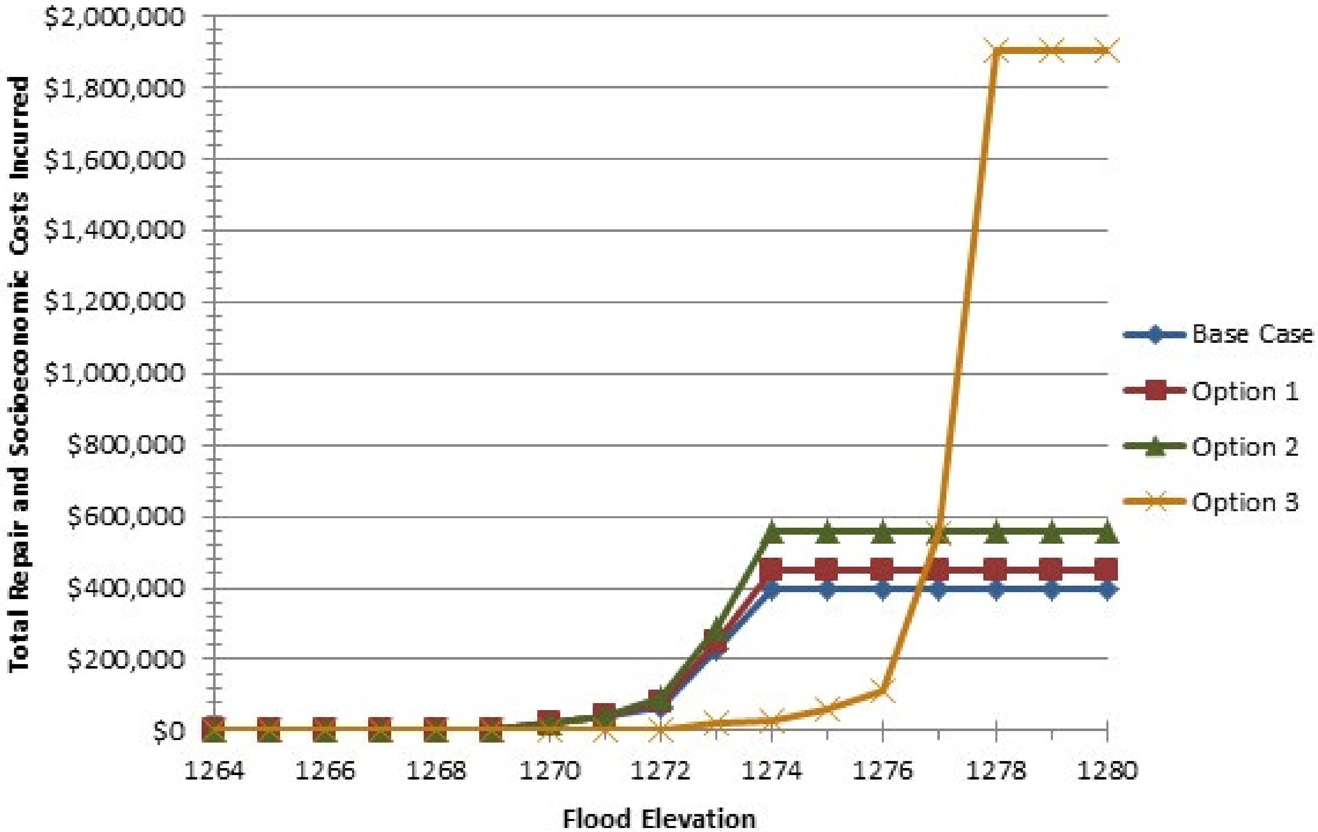


Figure 18: Depth-Damage Functions for the Culvert 5722 Design Options Without Social Costs

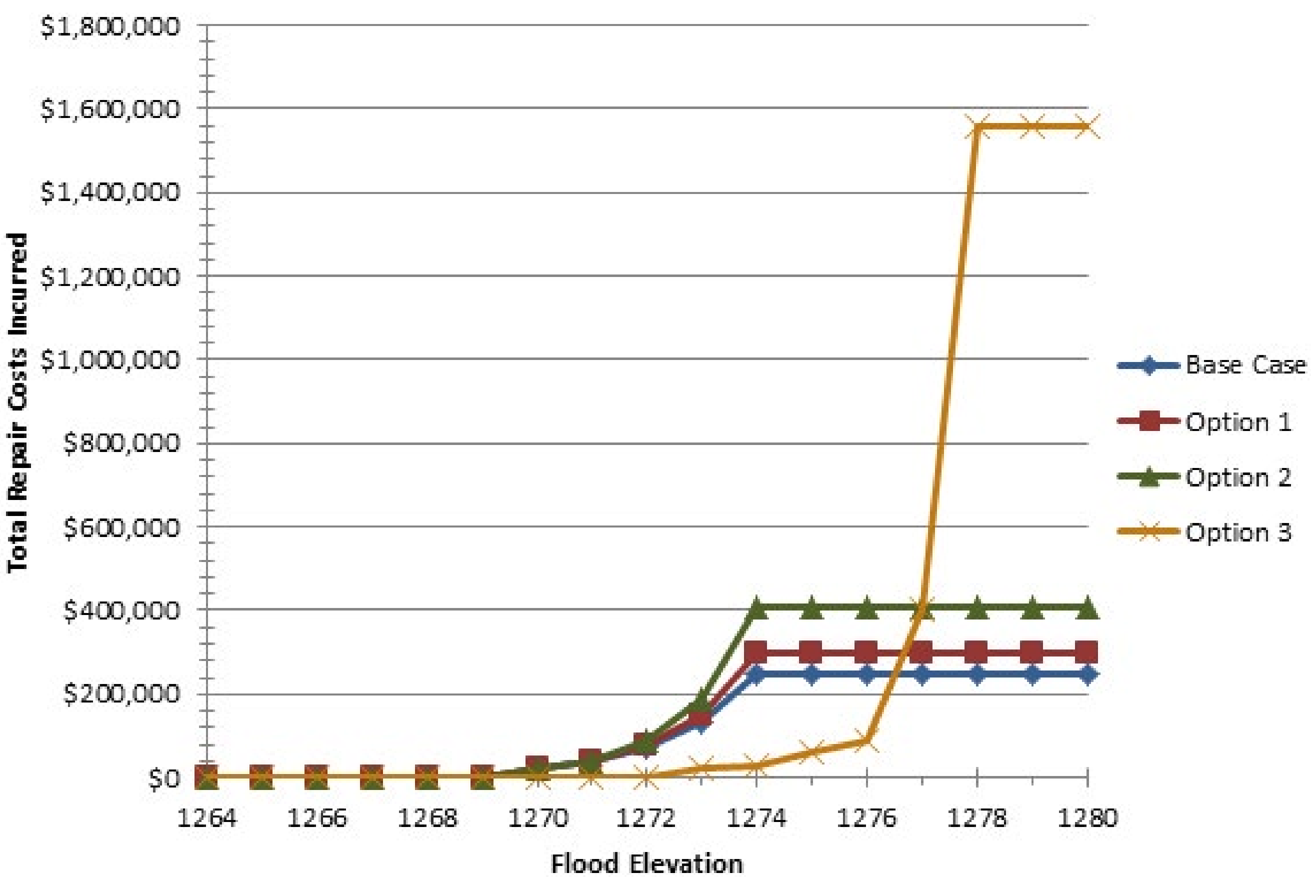


Table 6: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITHOUT Social Costs, Low Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	745,149	393,792	124,727	$291,712	$1,263,668	$1,555,380
Option 1: Add 2 cells	530,642	280,431	93,074	$566,040	$904,147	$1,470,187
Option 2: Add 2 cells & Floodplain Enhancement	395,233	238,715	75,609	$1,345,371	$709,557	$2,054,928
Option 3: 3 spaces @ 28 foot Bridge	5,636	2,979	933	$3,453,666	$9,548	$3,463,214

Table 7: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITHOUT Social Costs, Medium Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	745,149	423,625	134,176	$291,712	$1,302,950	$1,594,662
Option 1: Add 2 cells	530,642	247,275	93,074	$566,040	$870,991	$1,437,031
Option 2: Add 2 cells & Floodplain Enhancement	451,706	238,715	88,208	$1,345,371	$778,629	$2,124,000
Option 3: 3 spaces @ 28 foot Bridge	5,636	17,697	5,605	$3,453,666	$28,938	$3,482,604

Table 8: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITHOUT Social Costs, High Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	801,600	423,625	187,091	$291,712	$1,412,316	$1,704,028
Option 1: Add 2 cells	556,045	293,856	134,810	$566,040	$984,711	$1,550,751
Option 2: Add 2 cells & Floodplain Enhancement	451,706	337,942	107,038	$1,345,371	$896,686	$2,242,057
Option 3: 3 spaces @ 28 foot Bridge	5,636	2,979	933	$3,453,666	$3,463,214	$6,916,880

Table 9: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITH Social Costs, Low Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	1,049,983	554,889	175,752	$291,712	$1,780,624	$2,072,336
Option 1: Add 2 cells	662,357	350,039	116,538	$566,040	$1,128,934	$1,694,974
Option 2: Add 2 cells & Floodplain Enhancement	451,526	268,441	85,024	$1,345,371	$804,991	$2,150,362
Option 3: 3 spaces @ 28 foot Bridge	5,638	2,980	944	$3,453,666	$9,562	$3,463,228

Table 10: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITH Social Costs, Medium Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	1,049,983	584,722	185,201	$291,712	$1,819,906	$2,111,618
Option 1: Add 2 cells	662,357	367,936	116,538	$566,040	$1,146,831	$1,712,871
Option 2: Add 2 cells & Floodplain Enhancement	507,954	268,441	110,226	$1,345,371	$886,621	$2,231,992
Option 3: 3 spaces @ 28 foot Bridge	5,638	23,665	7,495	$3,453,666	$36,798	$3,490,464

Table 11: Projected Life Cycle Costs for Culvert 5722 Adaptation Option WITH Social Costs, High Scenario

	Period 1 2025-2055	Period 2 2056-2085	Period 3 2086-2100	Initial Construction Costs	Total Damage/Repair Costs by 2100	Total Life Cycle Cost by 2100
Base Case: Replace in Kind	1,106,434	584,722	307,408	$291,712	$1,998,564	$2,290,276
Option 1: Add 2 cells	696,224	367,936	160,647	$566,040	$1,224,807	$1,790,847
Option 2: Add 2 cells & Floodplain Enhancement	507,954	411,953	130,479	$1,345,371	$1,050,386	$2,395,757
Option 3: 3 spaces @ 28 foot Bridge	44,780	26,641	25,731	$3,453,666	$97,152	$3,550,818

Note: Options with the best life cycle cost-effectiveness are highlighted in green.

Figure 19: Cost Effectiveness of Culvert 5722 Adaptation Options Without Social Costs

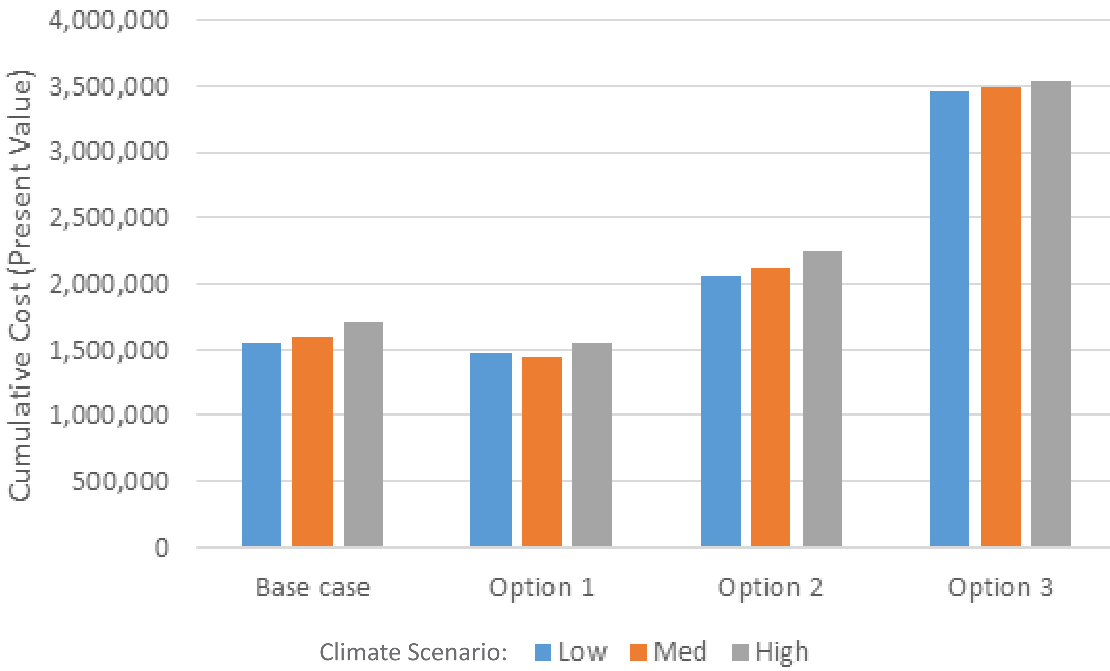
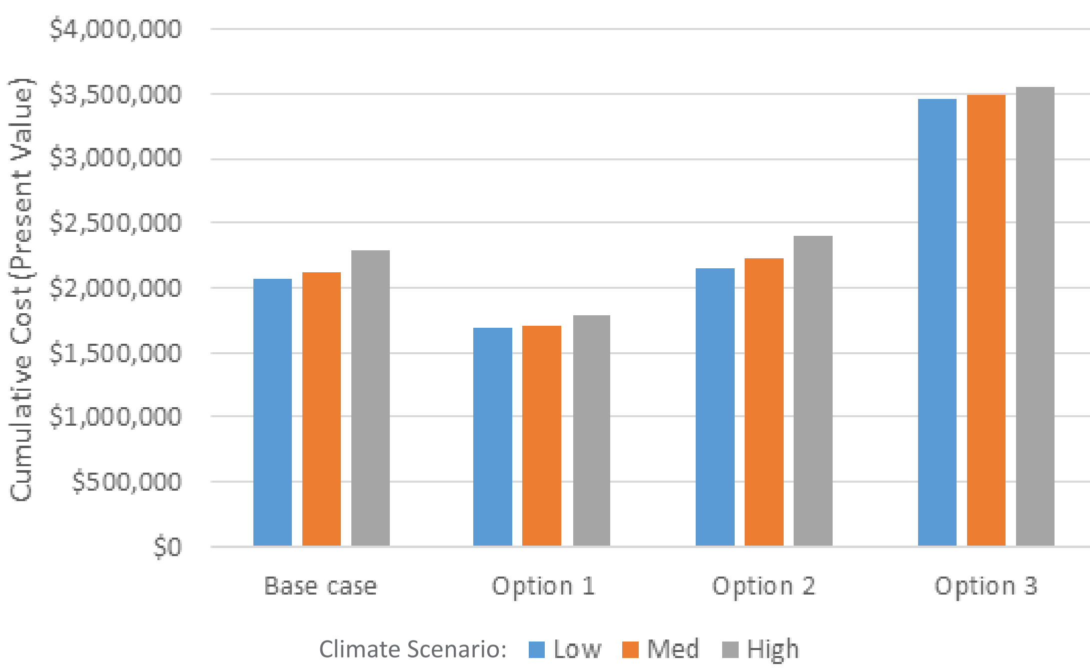


Figure 20: Cost Effectiveness of Culvert 5722 Adaptation Options With Social Costs



Step 9 – Evaluate Additional Decision-making Considerations

Potential additional decision making considerations that are of concern for the Spring Valley Creek culvert include upstream flood reduction benefits, total maximum daily load (TMDL)/water quality benefits, surrounding property impacts, historic and aesthetic value, maintenance of traffic, and on-going maintenance needs of the selected alternative. The pilot study project did not delve into each of these issues but specific points of consideration could include the historic railing on the existing culvert, the value of stream restoration on water quality, and the general utilization of the roadway.

A known issue is the presence of a historic railing on the current culvert structure. Regulatory requirements for the project may indicate that expansion of the existing culvert, rather than complete replacement, provides a more permissible treatment in regards to the railing. Option 2, which includes stream restoration and floodplain enhancement for the specific purpose of backwater reduction, will also provide benefits for water quality improvement due to stabilization of erosion areas and depositional opportunities for suspended solids and nutrients. This option would provide the department with water quality TMDL credits, if necessary, at a future time.

Each of these factors, along with other possible factors related to sustainability, permitting, project feasibility and practicality, ongoing maintenance needs, capital funds availability, and project risk should be considered along with the cost-effectiveness results, to select a design the provides the greatest value to the Department and the community.

Step 10 – Select a Course of Action

Based upon the results of Step 8, Option 1 is recommended for the site. However, additional conditions such as upstream flooding of private property, TMDL credit needs, and the project permitting requirements will need to be fully considered before a final course of action can be selected.

Step 11 – Plan and Conduct Ongoing Activities

After construction, facility performance should be monitored and recorded in an asset management database. As in the Silver Creek case study, specific items that should be recorded include frequency of overtopping, duration of closures, whether injuries resulted from the overtopping, and any damage costs. Instances where an adaptive design prevented the incurrence of costs relative to a traditional design should also be noted and a tally maintained of costs avoided. In the case of Culvert 5722, any changes in the flooding patterns of adjacent properties attributable to the design option chosen should also be monitored. All of this information will aid in future decision-making for this and other assets.

APPENDIX A | SPRING VALLEY COST ESTIMATES

EXISTING CONDITION | WORST CASE REPAIR COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$7,000	$7,000
Erosion Control	1	LS	$10,000	$10,000
Rip Rap (Outfall Scour Pool)	120	CY	$120	$14,400
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$10,000	$10,000
Storm Clean-up	1	LS	$30,000	$30,000
Excavation	30	CY	$30	$900
Structural Backfill	150	CY	$40	$6,000
Re-Set Culvert 3-cell (12'x6' ea)	1	LS	$50,000	$50,000
Culvert end section	3	EA	$8,500	$25,500
Pavement Restoration	120	Tons	$100	$12,000
Mobilization	1	LS	15%	$25,950
Contingency	1	LS	25%	$49,738
Total				$250,000

OPTION #1 | CONSTRUCTION COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$20,000	$20,000
Erosion Control	1	LS	$25,000	$25,000
Rip Rap	120	SY	$120	$14,400
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$25,000	$25,000
Demolition	1	LS	$25,000	$25,000
Excavation	250	CY	$30	$7,500
Structural Backfill	250	CY	$50	$12,500
Culvert 2-cell (12'x6' ea)	325	LF	$850	$276,250
Culvert end section	10	EA	$8,500	$85,000
Pavement Restoration	160	Tons	$100	$16,000
Mobilization	1	LS	8%	$41,108
Contingency	1	LS	25%	$138,740
Total				$690,000

OPTION #1 | WORST CASE REPAIR COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$7,000	$7,000
Erosion Control	1	LS	$10,000	$10,000
Rip Rap (Outfall Scour Pool)	120	CY	$120	$14,400
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$10,000	$10,000
Storm Clean-up	1	LS	$30,000	$30,000
Excavation	50	CY	$30	$1,500
Structural Backfill	150	CY	$40	$6,000
Re-Set Culvert 5-cell (12'x6' ea)	1	LS	$70,000	$70,000
Culvert end section	5	EA	$8,500	$42,500
Pavement Restoration	120	Tons	$100	$12,000
Mobilization	1	LS	15%	$31,590
Contingency	1	LS	25%	$60,548
Total				$300,000

OPTION #1 | DEPTH DAMAGE FUNCTION

Flood Elevation (Feet)	Physical Damage & Repair Cost	Socioeconomic Costs			Property	Total Cost	% Damage	Notes
		Detour		Injury				
		Days in Effect	Cost					
1264	$0	0	$0	$0	$0	$0	0%	
1269	$0	0	$0	$0	$0	$0	0%	
1270	$20,000	0	$0	$0	$0	$20,000	7%	Erosion Starts
1271	$40,000	0	$0	$0	$0	$40,000	13%	
1272	$80,000	1	$0	$0	$0	$80,000	27%	Overtopping Starts
1273	$150,000	5	$20,000	$80,000	$0	$250,000	83%	
1274	$300,000	15	$70,000	$80,000	$0	$450,000	150%	Full Breach of Roadway
1275	$300,000	15	$70,000	$80,000	$0	$450,000	150%	
1276	$300,000	15	$70,000	$80,000	$0	$450,000	150%	
1277	$300,000	15	$70,000	$80,000	$0	$450,000	150%	
1278	$300,000	15	$70,000	$80,000	$0	$450,000	150%	
1279	$300,000	15	$70,000	$80,000	$0	$450,000	150%	
1280	$300,000	15	$70,000	$80,000	$0	$450,000	150%	

OPTION #2 | CONSTRUCTION COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$20,000	$20,000
Erosion Control	1	LS	$25,000	$25,000
Rip Rap	120	SY	$120	$14,400
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$25,000	$25,000
Demolition	1	LS	$25,000	$25,000
Excavation	250	CY	$30	$7,500
Structural Backfill	250	CY	$50	$12,500
Culvert 2-cell (12'x6' ea)	325	LF	$850	$276,250
Culvert end section	10	EA	$8,500	$85,000
Pavement Restoration	160	Tons	$100	$16,000
Floodplain Enhancement Grading	18000	CY	$35	$630,000
Mobilization	1	LS	8%	$91,508
Property Acquisition	1	LS	$75,000.00	$75,000
Contingency	1	LS	25%	$327,590
Total				$1,640,000

OPTION #2 | WORST CASE REPAIR COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$7,000	$7,000
Erosion Control	1	LS	$10,000	$10,000
Rip Rap (Outfall Scour Pool)	120	CY	$120	$14,400
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$10,000	$10,000
Storm Clean-up	1	LS	$30,000	$30,000
Excavation	50	CY	$30	$1,500
Structural Backfill	150	CY	$40	$6,000
Re-Set Culvert 5-cell (12'x6' ea)	1	LS	$70,000	$70,000
Culvert end section	5	EA	$8,500	$42,500
Pavement Restoration	120	Tons	$100	$12,000
Floodplain Grading Repairs	2200	CY	$35	$77,000
Mobilization	1	LS	15%	$43,140
Contingency	1	LS	25%	$82,685
Total				$410,000

OPTION #2 | DEPTH DAMAGE FUNCTION

Flood Elevation (Feet)	Physical Damage & Repair Cost	Socioeconomic Costs			Property	Total Cost	% Damage	Notes
		Detour		Injury				
		Days in Effect	Cost					
1264	$0	0	$0	$0	$0	$0	0%	
1269	$0	0	$0	$0	$0	$0	0%	
1270	$20,000	0	$0	$0	$0	$20,000	7%	Erosion Starts
1271	$40,000	0	$0	$0	$0	$40,000	13%	
1272	$90,000	1	$0	$0	$0	$90,000	30%	Overtopping Starts
1273	$190,000	5	$20,000	$80,000	$0	$290,000	97%	
1274	$410,000	15	$70,000	$80,000	$0	$560,000	187%	Full Breach of Roadway
1275	$410,000	15	$70,000	$80,000	$0	$560,000	187%	
1276	$410,000	15	$70,000	$80,000	$0	$560,000	187%	
1277	$410,000	15	$70,000	$80,000	$0	$560,000	187%	
1278	$410,000	15	$70,000	$80,000	$0	$560,000	187%	
1279	$410,000	15	$70,000	$80,000	$0	$560,000	187%	
1280	$410,000	15	$70,000	$80,000	$0	$560,000	187%	

OPTION #3 | CONSTRUCTION COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$125,000	$125,000
Erosion Control	1	LS	$125,000	$125,000
Rip Rap (Abutment Protection)	80	CY	$120	$9,600
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$15,000	$15,000
Demolition	1	LS	$250,000	$250,000
Excavation	150	CY	$30	$4,500
Structural Backfill	150	CY	$40	$6,000
Multi Span Bridge	5544	SF	$150	$831,600
Assoc. Road and R-walls	1000	LF	$1,500	$1,500,000
Mobilization	1	LS	8%	$229,912
Property Acquisition	1	LS	$262,500.00	$262,500
Contingency	1	LS	25%	$841,578
Total				$4,210,000

OPTION #3 | WORST CASE REPAIR COST

	QTY	Unit	Unit Price	Total
Traffic Control	1	LS	$7,000	$7,000
Erosion Control	1	LS	$10,000	$10,000
Rip Rap (Abutment Protection)	80	CY	$120	$9,600
Guard Rail	120	LF	$60	$7,200
Stream Diversion	1	LS	$10,000	$10,000
Storm Clean-up	1	LS	$50,000	$50,000
Excavation	30	CY	$30	$900
Structural Backfill	150	CY	$40	$6,000
28 ft multi Span Bridge	5544	SF	$150	$831,600
Assoc. Road and R-walls	100	LF	$1,500	$150,000
Mobilization	1	LS	15%	$162,345
Contingency	1	LS	25%	$311,161
Total				$1,560,000

OPTION #3 | DEPTH DAMAGE FUNCTION

Flood Elevation (Feet)	Physical Damage & Repair Cost	Socioeconomic Costs			Property	Total Cost	% Damage	Notes
		Detour		Injury				
		Days in Effect	Cost					
1264	$0	0	$0	$0	$0	$0	0%	
1269	$0	0	$0	$0	$0	$0	0%	
1270	$0	0	$0	$0	$0	$0	0%	
1271	$0	0	$0	$0	$0	$0	0%	
1272	$0	0	$0	$0	$0	$0	0%	
1273	$20,000	0	$0	$0	$0	$20,000	1%	Erosion Starts
1274	$30,000	0	$0	$0	$0	$30,000	2%	
1275	$60,000	0	$0	$0	$0	$60,000	4%	
1276	$90,000	4	$20,000	$0	$0	$110,000	7%	Roadway Overtops
1277	$400,000	15	$70,000	$80,000	$0	$550,000	35%	Roadway Breach
1278	$1,560,000	60	$260,000	$80,000	$0	$1,900,000	122%	Foundation Failure
1279	$1,560,000	60	$260,000	$80,000	$0	$1,900,000	122%	
1280	$1,560,000	60	$260,000	$80,000	$0	$1,900,000	122%	