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Santa Cruz County Small Water Systems Connection Feasibility Analysis

Executive Summary

As the County of Santa Cruz pursues opportunities to ensure reliable and affordable water supply for all residents, one identified gap is whether and which types of physical and managerial collaborations between systems are feasible. This report examines two types of consolidation: physical interconnection of infrastructure and managerial consolidation of administrative and operational functions. It employs geographic mapping, cost modeling, and decision frameworks to evaluate feasible connection routes, estimate infrastructure and construction costs, and identify opportunities where consolidation could strengthen long-term system resilience. The findings will guide the County's ongoing efforts to support small water systems by identifying realistic consolidation opportunities that reduce compliance burdens, improve regional water reliability, and advance the drought-resilience goals outlined in SB 552. It also eliminates some systems from consolidation consideration as some costs are prohibitively high.

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Background and Justification

Small public water systems face significant challenges in maintaining reliable and safe drinking water due to regulatory requirements, financial constraints, infrastructure limitations, geophysical constraints, and water quality and quantity limitations. SB 552 introduces new mandates aimed at increasing the resilience of small public water systems as well as Nontransient-Noncommunity systems. These requirements include backup power by 2024, multiple water sources by 2027, metering of all service connections by 2032, and meeting fire flow capacity standards by 2032. While these measures improve long-term reliability, they also impose substantial financial and operational burdens on already resource-limited systems.

As a response to SB 552, the County of Santa Cruz developed the Drought Response Outreach Plan (DROP) which includes a Small Water Systems Support Plan (Plan) as part of its efforts to support small water systems in navigating these new requirements. While the DROP was only mandated to consider State Small Water Systems, which serve fewer than 15 connections, the County chose to consider the small public water systems under 200 connections as well. This Plan is intended to help by providing emergency support and also assistance with taking proactive steps to build resiliency and avoid emergency situations. The DROP highlights that small systems must meet many of the same regulatory obligations as large systems but lack the number of connections to spread costs effectively. The Plan identifies voluntary consolidation as a key strategy to improve resiliency and reduce compliance burdens. Consolidation allows smaller systems to merge with larger, more stable providers, benefiting from shared infrastructure, operational efficiencies, and improved water supply reliability.

The County's role in consolidation is facilitative rather than regulatory. While the State Water Resources Control Board (SWRCB) has authority to mandate consolidations in some cases of severe and persistent water quality violations, the preferred approach is voluntary consolidation, supported by decision-making tools and financial assistance. The DROP outlines the need for a decision-support tool to assess consolidation feasibility, providing small water systems with data-driven insights into the costs and benefits of potential connections.

This Connection Feasibility Analysis serves as a critical step in that process, evaluating the physical and managerial feasibility of consolidations across the County. By analyzing infrastructure requirements, cost factors related to constraints, and operational considerations, this study helps identify viable consolidation opportunities that align with SB 552's resilience objectives. The findings will contribute to the County's ongoing efforts to support small systems, improve regional water reliability, and develop sustainable solutions for long-term drought resilience.

Objectives and Scope

The purpose of this Connection Feasibility Analysis is to evaluate potential opportunities for connecting smaller water systems to larger, more resilient water systems in Santa Cruz County. The analysis primarily focuses on small systems that are viable candidates for consolidation with larger systems that already have extensive pipeline networks and support larger communities.

Systems included in an analysis fall into the following categories:

- **Individual Water Systems (1 to 4 connections):** These systems are regulated by the County Code (Chapter 7.73) and more information can be found here; Individual Water Systems
- **State Small Water Systems (5 to 14 connections):** These systems are regulated by the Drinking Water Regulatory program under both County Code (Chapter 7.71) and State laws and regulations. These systems are typically small in scale but may have the potential to benefit from consolidation with larger systems to increase resilience and reduce operational challenges.
- **Small Public Water Systems (15 to 199 connections):** Classified as Public Water Systems and regulated by both County Code (Chapter 7.71) and Federal and State law. Public Water systems incorporated into this analysis include two groups:
    - **Community Systems:** Serve full-time residences (homes)
    - **Non-transient, Non-community Systems:** Serve the same group of people over a long period of time (for schools only).
- **Large Water Systems (600+ Connections):** The following large water systems were considered as potential sources of reliable water in this analysis:
    - San Lorenzo Valley Water District
    - City of Watsonville
    - City of Santa Cruz
    - Scotts Valley Water District
    - Soquel Creek Water District
    - Central Water District

Considerations:

- The managerial analysis does not include State Small Water Systems, as managerial consolidation offers limited efficiency improvements—regulatory requirements are minimal and remain largely unchanged even after consolidation.
- Individual Water Systems (1 to 4 connections) were excluded from both the managerial and physical analysis due to their limited capacity and lack of resources for expansion or connection to larger systems. However, a separate proximity analysis was conducted for Individual Water Systems (see Sections 1.4, 3.4, and 5.0).
- Transient Non-Community Systems, such as campgrounds serving a variable group of people, were excluded.
- Physical interconnections between small water systems were not considered due to:
    - The low likelihood that a small system would have the capacity to supply another system without major infrastructure upgrades.
    - The uncertainty of water reliability, particularly during drought conditions, making smaller systems less dependable as a source for others.

This analysis focuses on two primary types of consolidation:

1. **Physical** – Merging water system infrastructure, such as distribution pipelines.
2. **Managerial (TMF)** – Involve the integration of administrative and operational functions between systems, which includes sharing billing, equipment, and staff or operators to streamline operations and reduce costs

The analysis follows a multifaceted approach:

- **Geographic and Infrastructure Constraints** – Geographic factors such as system locations, proximity to existing reliable water line infrastructure and established water service areas, and distances along road networks (physical connections) were analyzed. Additionally, travel times between systems (for managerial connections) and path conditions were considered to identify potential connection routes and assess operational overlaps.

- **Cost Estimation and Financial Factors** – A cost model was developed to estimate infrastructure and associated construction related costs with physical connections. This model incorporates variables such as slope, elevation changes, and groundwater conditions, and other geotechnical factors, providing an overview of the financial implications, particularly related to pipeline installation for consolidation.
- **Decision Framework**- Findings are presented through visual tools, including bar charts, maps, and matrices, to illustrate potential consolidation candidates and cost ranges. These tools help assess feasibility by providing comparative cost estimates, geographic relationships between systems, and key decision factors such as distance, infrastructure constraints, and operational considerations. This framework supports an at-a-glance evaluation of viable consolidation opportunities.

Data Sources

This The Connection Feasibility Analysis relies on a combination of geographic, geophysical, regulatory, and infrastructure datasets to assess potential consolidation opportunities. Key sources include:

- **Regulatory and Administrative Data** – Information from regulatory agencies, including water system classifications, water service area boundaries, sphere of influence boundaries (LAFCO), number of connections, operational status, and APN data.
- **Infrastructure Data** – Pipeline networks of large water systems and small water system locations sourced from local water agencies and the County's Local Primacy Agency respectively. Additionally, the road network within Santa Cruz County was used to evaluate potential connection pathways and estimate travel times between systems.
- **Hydrologic and Geotechnical Data** – Elevation data, groundwater conditions, landslide distributions, expansive soils, liquefaction susceptibility, and active fault traces were analyzed to assess terrain-related constraints and potential construction challenges.
- **LiDAR Data (2020):** High-resolution (2-foot) LiDAR (Light Detection and Ranging) data collected in 2020 to generate slope rasters and extract elevation data. LiDAR is a modern remote sensing technique that uses airborne laser measurements to generate highly detailed topographic data. This technology allows for the creation of bare-earth models by filtering out vegetation, providing an accurate depiction of the underlying terrain for hydraulic analysis.
- **Cost Estimation Data** – Pipeline installation cost estimates were derived from a California State Water Resources Control Board white paper report: *Draft White Paper Discussion on Proposed Drinking Water Cost Assessment Model Assumptions on Physical Consolidation (July 14, 2023).*

Tools

The Connection Feasibility Analysis was conducted using a combination of Geographic Information Systems (GIS) software and programming tools to process spatial data, perform geospatial analyses, and develop cost estimation models.

- **ArcGIS Pro** – Used for mapping, spatial analysis, and geoprocessing tasks such as proximity analysis, network analysis for travel time estimates, and spatial data visualization.

- **Python** – Used for data processing, automation, plotting, and geospatial analysis. Specific libraries include:
    - **arcpy**- Used for interacting with GIS data, such as accessing and modifying geospatital data and feature classes.
    - **pandas**- Used for data manipulation and analysis.
    - **matplotlib**- Used for creating plots and charts.
    - **numpy**- Used for numerical operations and arrays.
    - **os**- Used for interacting with the operating system.
    - **textwrap, locale, and seaborn-** Used for formatting and other visualization operations.

Methodology

The Connection Feasibility Analysis follows a systematic approach to evaluate potential consolidation opportunities for small water systems in Santa Cruz County. The methodology generally consists of three primary components: (1) spatial and infrastructure analysis, (2) cost estimation, and (3) decision framework development.

1. Spatial and Infrastructure Analysis

This step identifies potential consolidation opportunities by assessing the geographic distribution of small water systems, their proximity to larger systems, and the feasibility of physical and managerial connections. Key spatial analyses include:

1.1 Service Area and Infrastructure Mapping – Using GIS datasets from local water agencies and regulatory bodies, the pipeline networks (source) and small system locations (sinks) were mapped. This process involved the following steps:

1.1.1 Identifying Small Water System Locations (Sinks)

1. Import the existing County GIS layers containing Small Public Water Systems and State Small Water Systems.
2. Create a feature layer from an existing county-maintained data table containing latitude and longitude coordinates for a subset of system wells. These well locations serve as the sink points where potential pipelines would connect.
3. Perform a *Spatial Join* between the GIS feature layers and the county data table, using the water system number as the common field to link datasets.
4. Perform a number of *Calculate Field* operations to select only systems classified as "Community" (serving full-time residences) or "Non-Transient Non-Community (NTNC-School)" (e.g., schools). Export this subset into a new dataset, as these are the primary small systems considered for consolidation.
5. For systems lacking defined well locations:
    - Use the *Feature to Point Tool* on the polygon feature class associated with those water systems.

- Select the "Inside" option to generate a centroid point within each polygon, representing an assumed well location.
- Apply the *Add Locations* tool to integrate these newly generated points into the primary sink dataset.

1.1.2 Identifying Large Water System Infrastructure (Sources)

1. Obtain pipeline infrastructure datasets from large water systems in Santa Cruz County.
2. Extract water mains from these datasets, making minor refinements where necessary.
3. Manually place source points along key areas of the pipe network:
    - Position points at pipeline endpoints that extend closest to a particular small water system.
    - Review the road network in relation to target small systems to determine likely connection paths.
    - If likely closest source is unclear, place multiple potential source points along all possible routes to ensure the Closest Facility Analysis identifies the most efficient pathway.

1.1.3 Alternative Approach for Source Point Placement

- If cost and GIS processing credit usage are not constraints, an alternative automated method can be used:
    - Utilize the *Generate Points Along Lines* tool, setting an appropriate interval distance.
    - Combine these generated points with existing pipeline endpoints, which are typically the most likely potential tie-in locations.

1.2 Road Network and Distance Analysis for Physical Consolidation

Once the sink locations (small water systems) and source points (large system pipelines) were established, the county road network was analyzed to estimate the shortest feasible pipeline installation pathways. To perform this analysis, the *Closest Facility* tool within the *Network Analysis* framework was used. The setup included:

- Facilities: Potential source points along the pipeline distribution network (Section 1.1.2).
- Incidents: Presumed tie-in location (assumed to be the same as well location) for each small water system (Section 1.1.1).
- Travel Network: The analysis was constrained to an ESRI-defined road network, ensuring that pipeline pathways followed existing roads, as new pipeline infrastructure is typically installed along roadways.

The following parameters were applied:

- Maximum Travel Distance: Set at 50 km to prevent restrictions and ensure all feasible connections were considered.
- Number of Facilities to Find: Limited to 1, ensuring each small water system was assigned to the nearest large system pipeline.
- Road Restrictions: Highway 17 was designated as a line barrier due to the low feasibility of construction along or across this major roadway.

The output geometry represents the most direct and feasible pipeline installation pathways based on the road network constraints.

1.3 Road Network and Travel Time Analysis for Managerial Consolidation

The Managerial Connection Analysis aimed to evaluate the feasibility of consolidating management functions, such as administration, billing, and operational oversight, among Public Water Systems (PWS). This analysis was conducted using the *Closest Facility* tool within the *Network Analysis* framework, which identifies the nearest feasible managerial connections based on the drive travel time.

Analysis Setup:

- **Facilities & Incidents:** The same dataset, comprising PWS (74 total), was utilized for both facilities and incidents within the analysis. Each system was considered a potential facility or incident.
- **Travel Network:** The analysis was constrained to an ESRI-defined road network, similar to the physical connection analysis.
- **Maximum Travel Time:** A 60-minute cutoff was applied to identify feasible managerial connections within a reasonable timeframe.
- **Number of Facilities to Find:** The analysis was set to find a minimum of 9 potential facilities for each system.

The output geometry represents the most travel efficient managerial connections candidates based on the travel time.

1.4 Individual Water System Consolidation

This analysis evaluates the feasibility of transitioning a household from well water to a connection with a nearby large water system.

1.4.1 Determining Feasible Distance Limitations

The maximum feasible connection distance was determined using a formula derived from the State Water Board's *Draft White Paper Discussion on Proposed Drinking Water Cost Assessment Model Assumptions on Physical Consolidation* (July 14, 2023):

$$\begin{aligned}\text{Cost} = {} & \text{Regionally Adjusted Pipeline Cost} + \text{Regionally Adjusted Service Line Cost} \\ & + \text{Connection fees} + 10\%\ (\text{Planning \& Construction}) + 3\%(\text{Inflation})\end{aligned}$$

The total costs for at-risk domestic wells were adjusted for inflation (~6% over two years) and planning/construction costs (10%), applying these adjustments multiplicatively to reflect proportional increases. A benchmark cost of $50,000—representing the approximate cost of drilling a new domestic well in Santa Cruz County—was used to provide a realistic basis for justifying new connections, even for parcels with reliable, high-quality groundwater. Geotechnical and other site constraints were not included in this estimate.

The formula was then rearranged to solve for the maximum feasible pipeline length:

$$\text{Pipeline Length} = \frac{\frac{\text{Total Cost}}{1.06 \times 1.10} - \text{Service Line Cost} - \text{Connection Fee}}{\text{Pipeline Cost per Foot}}$$

By inputting $50,000 as the total cost and using the recommended values for service line costs ($6,200), pipeline costs ($220 per foot), and connection fees ($4,230) from the report, the equivalent connection distance to a large water system was calculated as approximately 150 feet.

1.4.2. Identifying Parcels within Reasonable Distance

To identify parcels located within 150 feet of a primary water main, the following datasets were used:

- **Parcels served by domestic wells** (Santa Cruz County GIS database)
- **Water mains of large water systems** (consistent with the physical consolidation analysis for small water systems)

A 150-foot *buffer* was applied to the water mains to define potential connection areas. A *pairwise intersect* was then performed, incorporating both the buffer and the domestic well parcel layer to identify overlapping parcels.

Since the domestic well parcel dataset is outdated, the initial results were refined by manually identifying and removing parcels known to served by city or district water providers.

Once the dataset was cleaned, a *spatial join* was conducted between the refined dataset and the original parcel layer, using a common identifier to link records. Finally, parcels within the 150-foot buffer were *extracted*, enabling clear visualization of parcels with potential connection opportunities.

2. Estimating Constraints Along Output Pipeline Paths

This section evaluates key constraints affecting pipeline feasibility and develops installation cost estimates for the proposed consolidation projects. Many of the estimates presented herein are expressed as percentage increases relative to the baseline pipeline cost of $310 per linear foot.

The baseline cost was initially estimated at $220 per linear foot based on the California State Water Resources Control Board's 2023 white paper. Following consultation with local water systems to better reflect current construction conditions in Santa Cruz County, the estimate was revised upward to $310 per linear foot to account for higher local construction costs.

2.1 Terrain Related Constraints

Geospatial datasets were incorporated to evaluate construction limitations and risks along potential pipeline routes:

2.1.1 Slope Analysis

To assess the impact of terrain on pipeline feasibility and cost, slope analysis was conducted using high-resolution 2020 LiDAR-derived elevation data. The analysis involved calculating slope values, extracting slope statistics along pipeline routes, and incorporating terrain-based cost adjustments. The key steps included:

1. Slope Calculation – A slope raster was generated from the 2020 DEM using the *Slope* tool in ArcGIS Pro, generating grid values in degrees.
2. Extracting Slope Values Along Pipeline Routes – The *Zonal Statistics as Table* tool was used to extract slope conditions along each pipeline segment.
    - The input was set to the extracted potential pipleline pathways from 1.2.
    - The slope raster was used as the value input.
    - The tool calculated the mean slope for each pipeline segment.
3. Joining Slope Data to Primary Route Dataset – The output table from the Zonal Statistics as Table tool was joined to the primary route dataset containing pipeline route attributes.
    - The *Join* was performed using a common identifier field linking pipeline segments to their corresponding slope statistics.
    - A *Calculate Field* operation was executed to transfer the mean slope values from the zonal statistics table to the dataset.
4. Slope Factor for Cost Adjustment – A cost adjustment factor was applied based on the mean slope values:
    - Determining Maximum Slope – To normalize cost adjustments, the maximum slope across all pipeline segments was identified using a scripted search function that iterated through all slope values. This maximum slope served as a reference for scaling cost adjustments.
    - A slope adjustment factor was applied to account for increased construction challenges in steeper areas. This factor was scaled between 1.0 (i.e. no impact for gentle slopes) and 1.15 (for the steepest terrain), to apply cost adjustments proportionally to terrain difficulty. The formula for computing the slope factor was:

$$SlopeFactor = 1.0 + \left(\frac{Slope(i) - 1.0}{MaxSlope - 1.0}\right) \times (1.15 - 1.0)$$

    The purpose of this equation is to ensure that the cost remains largely unchanged for paths with gentle slopes, while for steeper slopes, the cost is proportionally increased by up to 15% relative to the maximum slope.

    Incorporating Slope-Adjusted Costs – The slope factor was monetized relative to the base cost:

$$SlopeCost = (PipelineLength \times BaseCost \times SlopeFactor) - (PipelineLength \times BaseCost)$$

2.3 Pressure-Related Costs

Pressure related costs were determined by evaluating the elevation difference between the source and sink locations. For systems with an elevation difference of less than 50 feet (or ideally negative, gravity-fed), the existing pressure is assumed to be sufficient, and no additional cost is incurred. However, when the elevation difference exceeds 50 feet, the water pressure is assumed to drop and requires increased cost such as the installation of booster pumps to maintain flow.

2.3.1 Extracting Elevation at the Source and Sink

Elevation values were extracted at the source and sink locations using the DEM dataset and the *Extract Values to Points* tool in GIS.

- The elevation difference between the source and sink was *calculated* in GIS to determine if it exceeded 50 feet.

2.3.2 Elevation Cost Adjustment

The elevation difference is evaluated in a script, and if it exceeds 50 feet, a cost adjustment is applied.

- A 5% increase in cost relative to the base cost is added for each unit of pipeline length if it exceeds 50 feet.

2.4 Landslide-Related Costs

If a pipeline crosses a landslide, it can increase installation costs due to factors such as increased excavation depths, enhanced shoring requirements, higher backfill compaction requirements, the need for more robust piping materials, a higher frequency of trench plugs, and other construction-related mitigation costs. To assess landslide-related cost impacts, pipeline segments were analyzed for intersections with mapped landslide zones using geospatial data.

2.4.1 Identifying Landslide-Affected Pipeline Segments:

Landslide susceptibility was determined by evaluating whether modeled pipeline paths crossed mapped landslide areas based on the 1975 Cooper-Clark and Associates landslide inventory. The *Pairwise Intersect* tool in ArcGIS Pro was used to extract pipeline segments that overlapped these mapped landslides.

2.4.2 Cost Adjustment for Landslide Crossings:

For pipeline segments intersecting a mapped landslide, a cost adjustment factor was applied to account for additional engineering and material requirements. A 25% cost increase was assigned to these impacted length segments in a scripted calculation, roughly reflecting the increased engineering and material costs required for pipeline stabilization and risk mitigation.

2.5 Expansive Soils-Related Costs

If a pipeline crosses an area with expansive soils, installation costs can increase due to factors such as higher susceptibility to soil movement, increased structural reinforcement requirements, offhaul and import material cost for backfill, enhanced backfill compaction standards, and the need for more flexible or specially engineered piping materials. To assess cost impacts associated with expansive soils, pipeline segments were analyzed for intersections with mapped expansive soil zones using geospatial data.

2.5.1 Identifying Expansive Soil-Affected Pipeline Segments:

Expansive soil susceptibility was determined by evaluating whether modeled pipeline paths crossed mapped expansive soil areas based on a GIS layer maintained by the County of Santa Cruz GIS team. The *Pairwise Intersect* tool in ArcGIS Pro was used to extract pipeline segments that overlapped these mapped expansive soil areas.

2.5.2 Cost Adjustment for Expansive Soil Crossings:

For pipeline segments intersecting a mapped expansive soil zone, a cost adjustment factor was applied to account for additional engineering and material requirements. A 15% cost increase was assigned to these impacted length segments in a scripted calculation, roughly reflecting the additional construction measures needed to mitigate soil expansion and contraction risks.

2.6 Liquefaction-Related Costs

If a pipeline crosses an area susceptible to liquefaction, installation costs can increase due to factors such as enhanced shoring requirements (typically loose sands), higher backfill compaction standards, the need for more flexible or specially engineered piping materials, and additional stabilization measures. To assess cost impacts associated with liquefaction, pipeline segments were analyzed for intersections with mapped liquefaction zones using geospatial data.

2.6.1 Identifying Liquefaction-Affected Pipeline Segments

Liquefaction susceptibility was determined by evaluating whether modeled pipeline paths crossed mapped liquefaction areas based on a GIS layer maintained by the County of Santa Cruz GIS team. The *Pairwise Intersect* tool in ArcGIS Pro was used to extract pipeline segments that overlapped these mapped liquefaction areas.

2.6.2 Cost Adjustment for Liquefaction Crossings

For pipeline segments intersecting a mapped liquefaction zone, a cost adjustment factor was applied to account for additional engineering and material requirements. A 30% cost increase was assigned to these impacted length segments in a scripted calculation, roughly reflecting the increased construction measures needed to mitigate soil liquefaction risks during seismic events.

2.7 High Groundwater-Related Costs

If a pipeline crosses an area with high groundwater, installation costs can increase due to factors such as increased dewatering requirements, enhanced shoring, additional trench stabilization, higher backfill compaction standards, and the need for corrosion-resistant piping materials. To assess cost impacts associated with high groundwater, pipeline segments were analyzed for intersections with mapped high groundwater areas using geospatial data.

2.7.1 Identifying High Groundwater-Affected Pipeline Segments:

High groundwater susceptibility was determined by evaluating whether modeled pipeline paths crossed mapped high groundwater areas based on a GIS layer maintained by the County of Santa Cruz GIS team. The *Pairwise Intersect* tool in ArcGIS Pro was used to extract pipeline segments that overlapped these mapped high groundwater areas.

2.7.2 Cost Adjustment for High Groundwater Crossings:

For pipeline segments intersecting a mapped high groundwater zone, a cost adjustment factor was applied to account for additional engineering and material requirements. A 20% cost increase was assigned to these impacted length segments in a scripted calculation, roughly reflecting the increased construction measures needed to manage high groundwater and maintain trench stability.

2.8 Active Fault Trace-Related Costs

If a pipeline crosses an active fault trace, installation costs can increase due to factors such as the need for specialized seismic design, enhanced joint flexibility, additional trench stabilization, and other fault rupture mitigation measures. To assess cost impacts associated with active faults, pipeline segments were analyzed for intersections with mapped active fault traces using geospatial data.

2.8.1 Identifying Active Fault-Affected Pipeline Segments:

Active fault trace susceptibility was determined by evaluating whether modeled pipeline paths crossed mapped active fault traces based on USGS fault data. The *Pairwise Intersect* tool in ArcGIS Pro was used to extract pipeline segments that overlapped these mapped fault traces.

2.8.2 Cost Adjustment for Active Fault Crossings:

For pipeline segments intersecting a mapped active fault trace, a fixed cost increase of $100,000 was applied in a scripted calculation. This rough adjustment reflects the additional construction measures needed to enhance pipeline resilience against fault displacement and seismic activity.

2.9 Path Overlap Adjustments

The cost adjustments described in 2.4-2.8 apply to pipeline pathways crossing only one constraint criterion. However, when pipeline pathways intersect multiple criteria (e.g. landslide area and high groundwater zone), costs must be adjusted to prevent overestimation due to overlapping factors. If not accounted for, overlapping conditions could lead to double counting, triple counting, or other forms of overestimation, resulting in exaggerated cost estimates. To manage these cases, the total length for each criterion is adjusted to exclude segments where it overlaps with another constraint, where those situations are handled separately. This ensures that each impacted section is only counted once while still incorporating the increased complexity of construction and mitigation efforts.

2.9.1 Length Adjustments for Overlapping Constraints

The following generic approach is used to adjust pipeline segment lengths (see 2.9.3 for detailed approach):

- **Single-Criteria Segments:** Pipeline segments intersecting only one constraint are adjusted by subtracting overlapping portions that also fall under another constraint.
- **Double Overlap Segments:** Segments affected by two overlapping constraints are extracted and scaled separately.
- **Triple Overlap Segments:** The limited cases where three constraints overlap (liquefaction, expansive soils, and high groundwater) are extracted and scaled separately.
- **Unimpacted Pipeline Length:** Segments that do not intersect any constraint are identified and calculated by subtracting all impacted segments from the total pipeline length.

  In Santa Cruz County, only one triple-overlap scenario was identified, involving liquefaction, expansive soils, and high groundwater. No instances of quadruple or higher overlaps were found in the county.

  Pipeline lengths are analyzed using the *Pairwise Intersect* tool in ArcGIS, and the adjusted lengths are then passed to a script for cost factor calculations. The following sections provide a detailed breakdown of the adjustment methodology and cost factor scaling for overlapping conditions.

2.9.2 Cost Factor Adjustments for Overlapping Conditions

The cost factors for overlap conditions are scaled rather than summed. This is because mitigation efforts often involve overlapping strategies, meaning the costs should increase but not necessarily at a rate equal to the sum of individual criteria. The general cost adjustments follow this logic (see 2.9.4 for detailed approach):

- **Unimpacted Segments:** The base cost is applied to the pipeline length that does not intersect any constraints.
- **Single-Criteria Cost:** Each constraint has its own cost factor (Appendix C) applied to the adjusted length.
- **Double Overlap Cost:** The cost factor for double overlaps is calculated as the average of the two criteria's cost factors, scaled by an additional adjustment factor (Appendix C).
- **Triple Overlap Cost:** The cost for triple overlap areas (liquefaction, expansive soils, and high groundwater) is computed as the average of the three criteria's cost factors, further scaled by a multiplier (Appendix C).

Detailed Path Overlap Adjustments

Building on the framework outlined in 2.9.1 and 2.9.2, this section provides a step-by-step breakdown of the methodology used to adjust pipeline segment lengths and prevent cost overestimation.

2.9.3 Detailed Length Adjustments for Overlapping Constraints

The pipeline overlap lengths are extracted using the *Pairwise Intersect* tool in ArcGIS and are then processed in a script to adjust the length calculations for each record.

Single-Criteria Segments: The length for each constraint is adjusted by subtracting overlapping portions where the pipeline crosses another constraint. This includes:

- Double Overlaps (e.g., landslide + liquefaction)
- Triple Overlaps (e.g. landslide + liquefaction + groundwater)

Since the *Pairwise Intersect* extraction of the pipleline path and geohazard constraint layer captures all overlap scenarios alongside single-constraint segments, and cost adjustments for these overlapping segments are handled separately, they need to be fully subtracted from each individual constraint calculation. For each record, the adjusted single-criteria lengths are computed as follows:

- Adjusted **landslide length**:

$$ls\_length\_total - (ls\_exp\_length + ls\_liq\_length + ls\_gw\_length)$$

- Adjusted **liquefaction length**:

$$liq\_length\_total - \ (exp\_liq\_length + gw\_liq\_length + ls\_liq\_length) + \left(liq\_exp\_gw\_length(if applicable)\right)$$

- Adjusted **expansive soil length**:

$$exp\_length\_total - (exp\_liq\_length + exp\_gw\_length + ls\_exp\ length) + \left(liq\_exp\_gw\_length\ (if\ applicable)\right)$$

- Adjusted **groundwater length**:

$$gw\_length\_total - (gw\_liq\_length + exp\_gw\_length + ls\_gwlength) + \left(liq\_exp\_gw\_length(if applicable)\right)$$

Double-Criteria Segments

In addition to single-criteria segments, some pipeline segments are impacted by two or more overlapping constraint criteria, such as:

- Double Overlaps (e.g., landslide + liquefaction, expansive soil + groundwater)
- Triple Overlaps (e.g., landslide + liquefaction + groundwater)

Since the *Pairwise Intersect* extraction for double-criteria paths includes both double-overlapping and triple-overlapping segments where multiple criteria share the same path, and because cost adjustments for triple-overlap scenarios are handled separately, the triple-overlap sections must be fully subtracted from each individual double-constraint calculation. For each record, the adjusted double-criteria lengths are computed as follows:

- **Landslide & Expansive Soils:**

$$ls\_exp\_length(nofurtheradjustment)$$

- **Landslide & Liquefaction:**

$$ls\_liq\_length(nofurtheradjustment)$$

- **Landslide & Groundwater:**

$$ls\_gw\_length(nofurtheradjustment)$$

- **Expansive Soils & Groundwater:**

$$exp\_gw\_length - \left(liq\_exp\_gw\_length(ifapplicable)\right)$$

- **Expansive Soils & Liquefaction:**

$$exp\_liq\_length - \left(liq\_exp\_gw\_length(ifapplicable)\right)$$

- **Groundwater & Liquefaction:**

$$gw\_liq\_length - \left(liq\_exp\_gw\_length(ifapplicable)\right)$$

Triple-Criteria Segments

Since the *Pairwise Intersect* extraction for three overlapping criteria does not include scenarios with four or more overlapping constraints, the triple-overlap length is directly determined from the extracted dataset. Unlike single- and double-overlap adjustments, no additional subtractions are required, as there are no cases in the county where more than three constraints overlap.

Note: There are no triple-overlap areas in the county involving landslides.

For triple-overlap scenarios, the extracted length is derived from the intersection of:

- **Double-overlap paths** (e.g., expansive soils + groundwater)
- **Single-constraint paths** (e.g., liquefaction)

For each record, the triple-overlap length is computed as follows:

$$adjuste\_triple\_overlap\_length = liq\_exp\_gw\_length$$

Since liq_exp_gw_length represents the segment where all three constraints (liquefaction, expansive soils, and groundwater) overlap, no further modification is needed.

- **Unimpacted Pipeline Length:** The total pipeline length that does not cross any constraint is calculated by subtracting all impacted segment lengths from the total pipeline length:

$$unimpacted\_length = total\_length - \left(\sum adjusted\ single, double, and\ tripleoverlaplengths\right)$$

While more than three constraints could theoretically overlap in other locations, no cases of quadruple or higher overlaps were found in the county.

2.9.4 Detailed Cost Factor Adjustments for Overlapping Conditions

The detailed cost adjustments implemented in the script (Appendix C) follow this logic:

- **Unimpacted Segments:**

$$unimpacted\_length \times base\_cost$$

- **Single-Criterion Cost:**

$$adjusted\ length \times base\ cost \times corresponding\ factor$$

- **Double Overlap Cost:**

$$adjusted\ double\text{-}overlap\ length \times \frac{(factor_1 + factor_2)}{2} \times double\ overlap\ factor \times base\ cost$$

- **Triple Overlap Cost (only liquefaction, expansive soils, and groundwater):**

$$triple\_overlap\_length \times \frac{(liquefaction\ factor + expansive\ soils\ factor + groundwater\ factor)}{3} \times triple\_overlap\_factor \times base\ cost$$

- **The total project cost is then computed as follows:**

$$TotalCost = Non\_ImpactedCost + \sum Single\_CriterionCosts + \sum Double\_OverlapCosts + \sum Triple\_OverlapCosts$$

3.0 Visualization

The visualization of the results focuses on representing the potential cost savings and risk factors associated with water system consolidation, using bar charts, heatmaps, and maps to illustrate the findings:

3.1 Stacked Bar Chart for Cost Breakdown

The stacked bar chart (Appendix A) displays the breakdown of total costs for each record. The x-axis labels represent water systems, including their names, and the number of existing connections shown in parentheses to provide context, which is intended to help evaluate the feasibility of consolidation, as more connections may imply greater financial resources or reserves. Each bar segment represents a different cost factor, such as non-impacted costs, landslide costs, expansive costs, etc. The total height of each bar reflects the overall cost for that particular system connection. To identify potential cost-saving opportunities, an overlap area is shown within the chart, represented as a hatch pattern. This area indicates overlap from one or more water systems that share a potential pipeline path, intended to convey that if these systems pool their resources, they could save on installation costs.

3.2 Heatmap for Managerial Connection Travel Time

A heatmap (Appendix B) was used to visualize travel times between water systems for managerial connections, providing a general overview of travel time patterns and helping decision-makers assess the feasibility of merging operations. The heatmap is structured as a matrix that plots travel times between different systems using a color-coded scale:

- Green (0–10 minutes) – Close proximity, facilitating easier managerial coordination
- Orange (10–20 minutes) – Moderate travel time, involving more logistical planning
- Red (20–30 minutes) – Longer travel time, potentially complicating managerial consolidation

This visualization helps identify which systems are geographically closest to one another, offering insights into the practicality and efficiency of administrative integration across different systems.

3.3 Map for Physical Consolidation

The map (Plate 1) visualizes the feasibility of physically connecting small water systems to larger regional infrastructure, focusing on the primary driver of cost: distance to tie-in points on major water mains. Several key elements are highlighted in the map:

- Water Mains: Color-coded by system to show the regional distribution infrastructure.
- Small Water Systems: These are categorized by connection size and location relative to water service areas.
- Distance to Water Mains: Color gradients represent proximity to water mains, with darker colors indicating closer proximity and lighter colors indicating greater distances. This highlights the accessibility challenges faced by small systems that are further away from existing infrastructure.
- Overlapping Paths: Dashed purple lines identify shared routes between systems, indicating potential cost-saving opportunities if multiple systems can coordinate and consolidate resources along the same pipeline routes.

3.4 Map for Individual Water Systems Proximity Analysis

This map (Plate 2) identifies parcels currently served by domestic wells that are within 150 feet of a water service line from a large water system. Key features include:

- Parcels served by wells (yellow) – Indicating properties that rely on private well water.
- Proximity Zone (red) – The portion of each parcel that falls within the 150-foot buffer from a water main, highlighting feasible connection areas.

- Water Mains – Color-coded by system to illustrate regional distribution infrastructure.

Small Water System Results

A total of 85 water systems were included in the physical consolidation analysis (Plate 1). One system that initially met the inclusion criteria was ultimately eliminated because its only road network path to a large water system required crossing Highway 17, a designated path barrier, rendering its connection infeasible.

Key Findings

- **Distance to Water Mains:**
  - The average distance from small water systems to the nearest water main is approximately 12,500 feet, while the median distance is around 6,500 feet.
  - Given the baseline cost of $310 per linear foot, distance represents the primary cost driver and a significant limiting factor for physical connections in the county.
- **Terrain and Slope:**
  - The average slope along potential pipeline paths is 8.9°, associated with moderately sloping topography.
- **Connections and Shared Pathways:**
  - On average, there are 31 connections per system.
  - Approximately 56 of the 85 systems share at least one common pipeline path with another system.
    - Among these, the average percent overlap is around 65%, although the overall average overlap across all systems is 43%.
    - Furthermore, 30 systems share a path with two or more systems, indicating considerable potential for resource pooling and cost-sharing.
- **Geotechnical Constraints:**
  - Only 3 systems have potential pipeline paths that cross an active fault—specifically, the San Andreas Fault—minimizing the seismic design challenges in most areas. A fault is considered active if they have moved within the last 10,000 years.
  - The liquefaction criterion was found to be the largest contributor to increased costs (aside from distance), impacting 53 systems.
  - Approximately 50% of the total potential pipeline length is impacted by at least one geotechnical constraint, underscoring the widespread nature of these challenges.
- **Pressure and Elevation Differences:**

    - The pressure differences between systems range from -181 feet (ideal, as gravity-fed systems are more cost-effective) to 2,062 feet (which significantly raises installation costs due to the need for booster pumps and additional infrastructure).
    - The median pressure difference is 88 feet, and only 14 systems have negative pressure differences, indicating that the majority of systems will require extra measures to manage water pressure deficiencies.
- **Regulatory and Administrative Considerations:**
    - Only 3 of the 86 small water systems that met the analysis criteria are located within existing water service areas, suggesting that most systems face additional regulatory and administrative challenges. 19 small water systems were identified to be within a sphere of influence boundary administered by LAFCO.
- **Cost Estimates:**
    - The average estimated physical pipeline cost is approximately $3,400,000, with a median cost of around $1,750,000.
    - Total project costs range widely from about $16,000 to nearly $17,000,000, reflecting the variability in required pipe length, geotechnical conditions, and required infrastructure enhancements in order to connect or develop an emergency intertie to a more reliable water source.
    - These costs do not include design, permitting, or mitigations, which can be substantial.

Managerial Connection Feasibility

While physical consolidation presents substantial financial and logistical challenges, managerial connections offer a more immediate and cost-effective alternative for improving small water system sustainability.

- **Proximity of Managerial Connections:**
    - Out of 74 public water systems evaluated for managerial connections, 61 have at least one potential connection within 10 minutes of travel time.
    - Among these, 34 systems have at least 3 viable managerial connections within 10 minutes.
- **Connection Density:**
    - The average number of managerial connections per system that are within 10 minutes is 3.2.
    - This suggests that many small systems are clustered close enough to benefit from shared administrative resources, potentially reducing operational costs and improving service reliability.

For a detailed breakdown of specific managerial connection opportunities, Appendix B provides a matrix plot illustrating travel times between different systems.

Summary of Findings

These results highlight the significant challenges of physical consolidation, primarily due to high costs driven by distance and geotechnical constraints. However, in contrast, the considerable sharing of pipeline paths among systems suggests substantial potential for cost savings if collaborative approaches are adopted. Systems that share pipeline segments could pool resources to reduce installation costs, making physical consolidation more financially viable in some cases.

Meanwhile, managerial connections offer a promising alternative, with a majority of systems having viable opportunities for administrative and operational collaboration within a short travel time, underscoring the importance of exploring managerial integration as a near-term strategy while continuing to assess long-term physical consolidation feasibility.

Individual Water System Results

Approximately 8,400 parcels in Santa Cruz County are currently served by domestic wells. Following the analysis described in Section 1.4, a total of 605 parcels were identified as being within a feasible distance for connection to a large water system.

The results highlight a number potential opportunities for transitioning domestic well users to a more reliable water supply. However, feasibility depends on additional factors such as regulatory requirements, variable financial situations, and site-specific property constraints, which are larger uncertainties. Plate 2 provides a visual representation of the identified parcels and their proximity to existing water mains.

Limitations

- Baseline pipeline costs were initially estimated at $220 per linear foot based on the California State Water Resources Control Board's 2023 white paper. After consulting with local water systems to better reflect current conditions in Santa Cruz County, this estimate was revised upward to $310 per linear foot to account for local construction costs.
- This estimate is inherently approximate and reflects general local construction cost conditions. The State Water Board's 2023 report recommends a range of $155 to $220 per linear foot, and actual project costs may vary depending on site-specific conditions.
- Geotechnical criteria factors, which have a potentially significant impact on cost estimates, are primarily judgment-based. They are intended to recognize the likelihood of increased costs when encountering geotechnical constraints rather

than providing precise cost adjustments. For specific cost factors associated with each constraint, refer to the script (Appendix C).

- The geotechnical criteria are based on the best available data layers for the county, but actual field conditions may vary significantly.
- Additional geotechnical factors that were not explicitly considered could further impact costs. For example, subsurface materials could influence excavation feasibility, trench stability, and necessary shoring requirements. Other factors, such as sensitive habitats that may require construction restrictions, additional mitigation, or permitting considerations, could also contribute to cost variability.
- Pressure-related costs are generalized, applying the same additional costs to all systems that exceed the minimum 50-foot elevation threshold. In reality, systems located significantly higher in elevation than their connection point are likely to incur substantially greater costs than those closer to the 50-foot threshold. A more refined approach could scale costs based on elevation differences, similar to the cost adjustment methodology used for slope factors, while also accounting for the necessary infrastructure to manage varying pressure demands. Additionally, pressure calculations were simplified by considering only the difference between sink and source elevations, meaning a negative elevation difference suggests a more cost-effective, gravity-fed system could be utilized. However, this approach does not fully capture variations in topography along the pipeline route. For example, an initial uphill climb before a subsequent downhill drop may still necessitate pressure enhancing infrastructure, even if the overall elevation difference appears favorable for gravity flow.
- The cost estimates are based on generalized unit costs and do not account for site-specific challenges such as traffic control, right-of-way constraints, permitting fees, or seasonal construction limitations.
- Pipeline installation is assumed to follow the existing road network. However, actual pipeline paths may vary based on site-specific constraints.
- Distance calculations include only the pipeline length along the road network up to the point where it is perpendicular to the defined well source. They do not account for the additional pipeline length required from the street to the actual water tie-in point on the property. Additionally, well source locations may be inaccurate, particularly for systems where the county lacked precise location data and had to default to locations based on parcel centroids.
- The cost estimates provide a general ballpark figure for potential costs across most systems in the county, given that distance is the primary cost driver.
- The pipeline cost estimates consider only installation costs. Other costs, such as service line installation, connection fees, administrative costs, CEQA compliance, contingency adjustments, regional cost adjustments, planning and construction factors, and inflation, must be considered for a full project cost estimate. These additional costs are detailed in the California State Water Resources Control Board's white paper report.

- The State Water Board also identifies additional potential costs not explicitly covered in their report, including expenses related to technical assistance, administration, and other regulatory requirements.

References

California State Water Resources Control Board. *Draft White Paper Discussion On: Proposed Drinking Water Cost Assessment Model Assumptions on Physical Consolidation (2023)*. Retrieved from https://www.waterboards.ca.gov

Plates

- **Plate 1.** Physical Consolidation Map – Small Water Systems
- **Plate 2.** Proximity Map for Individual Water Systems

Appendices

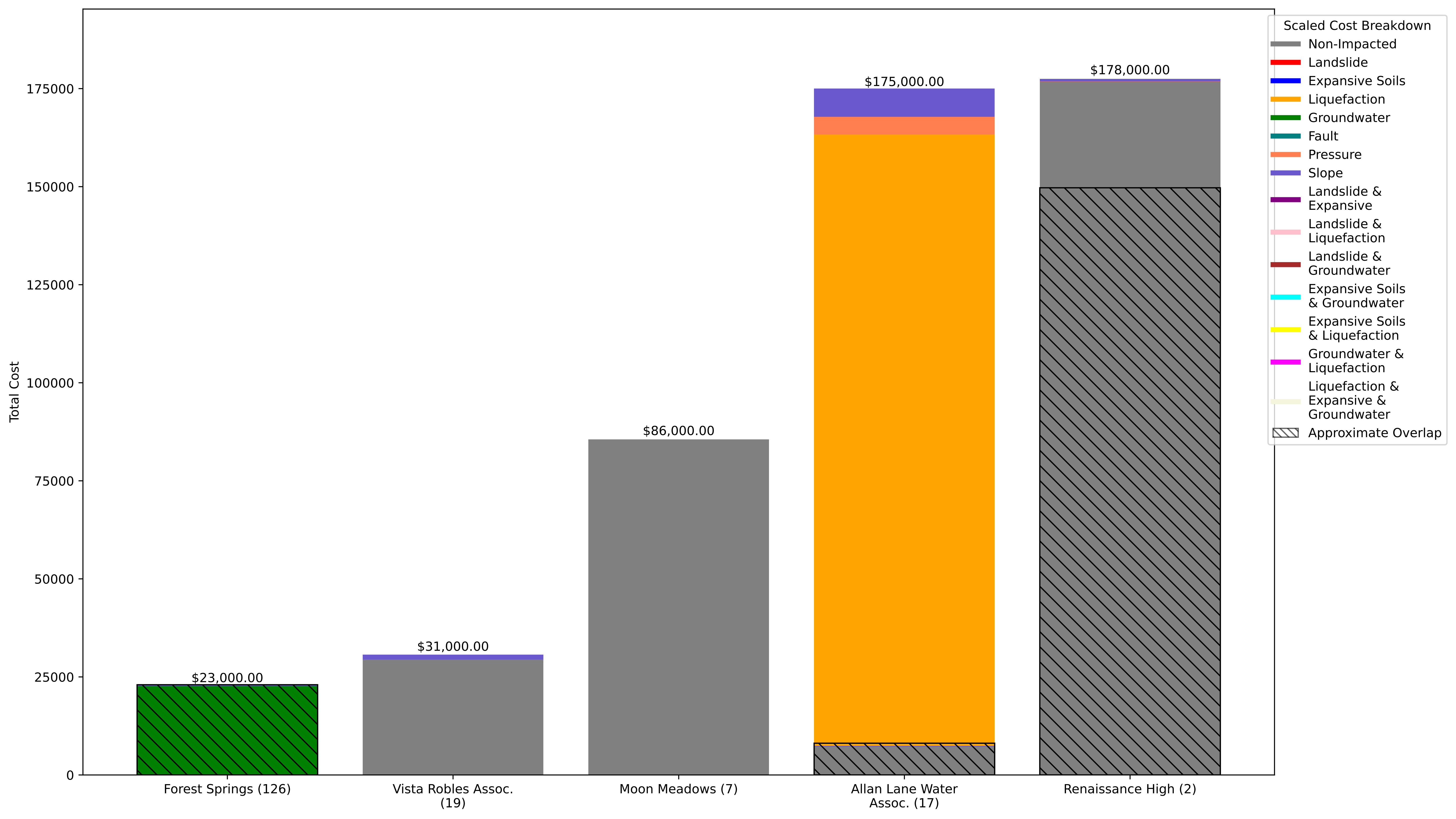
- **Appendix A.** Stacked Bar Chart Showing Cost Breakdown
- **Appendix B.** Heat Map of Managerial Connection Travel Time
- **Appendix C.** Scripts Used to Generate Cost Factors and Stacked Bar Charts

PLATE 1

Legend
San Lorenzo Valley Water Mains
Watsonville Water Mains
City of Santa Cruz Water Mains
Scotts Valley Water Mains
Soquel Creek Water Mains
Central Water Mains
Small_Water_Systems
100 - 186 Connections (Outside WSA)
15 - 100 Connections (Outside WSA)
0 - 14 Connections (Outside WSA)
15 - 100 Connections (Inside WSA)
0 - 14 Connections (Inside WSA)
Distance to Water Main
0 - 2000 feet
2000 - 5000 feet
5000 - 65637 feet
Overlapping Paths
Large Water System (200+ connections)
N
0 0.5 1 2 3 4 Miles
County of Santa Clara, County of Santa Cruz, Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, EPA, USDA

PLATE 2


N
0 2,500 5,000 10,000 15,000 20,000
Feet
Legend
Parcel-Buffer Overlap Zone
Parcels Served by Domestic Wells
Water Main



Total Cost
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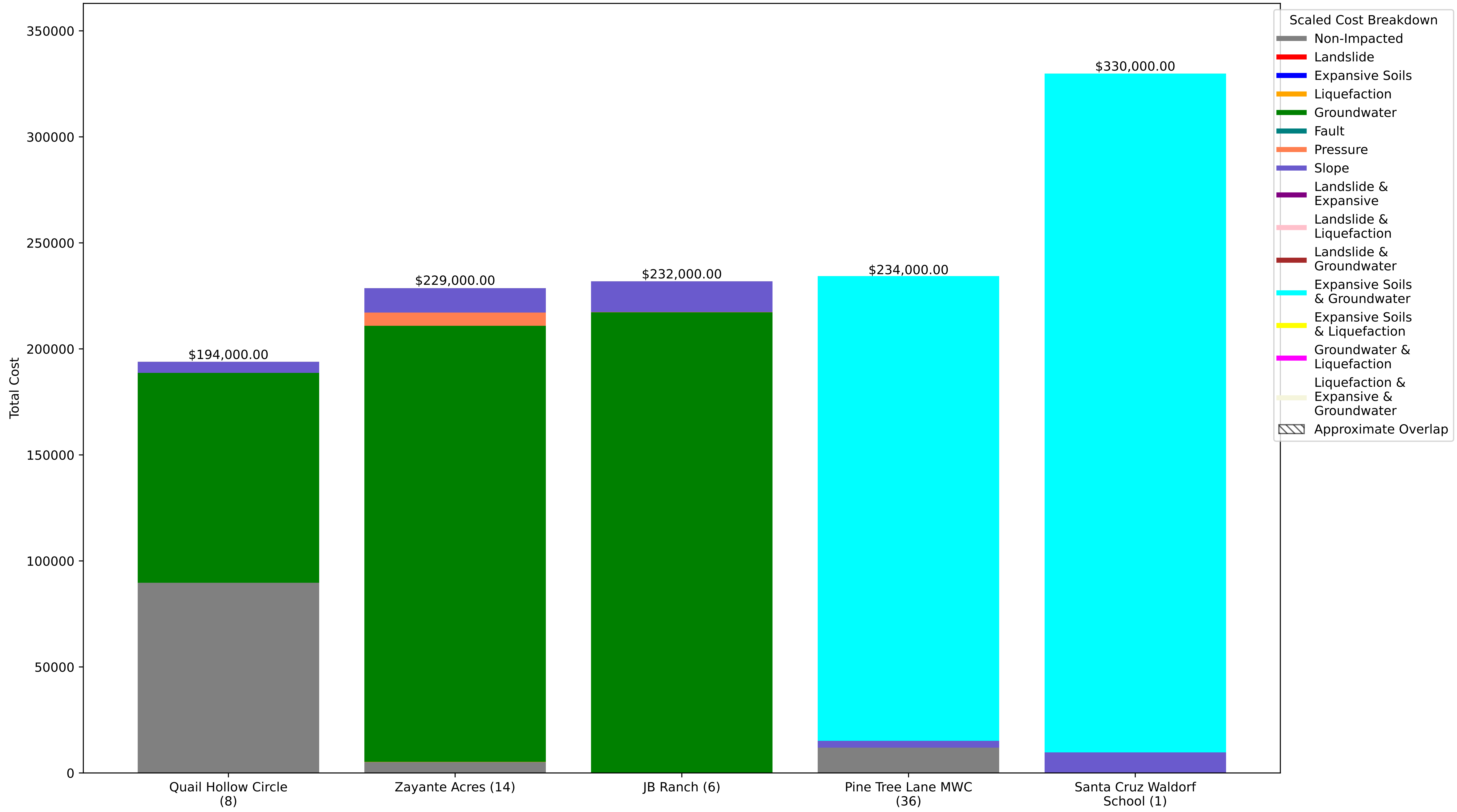
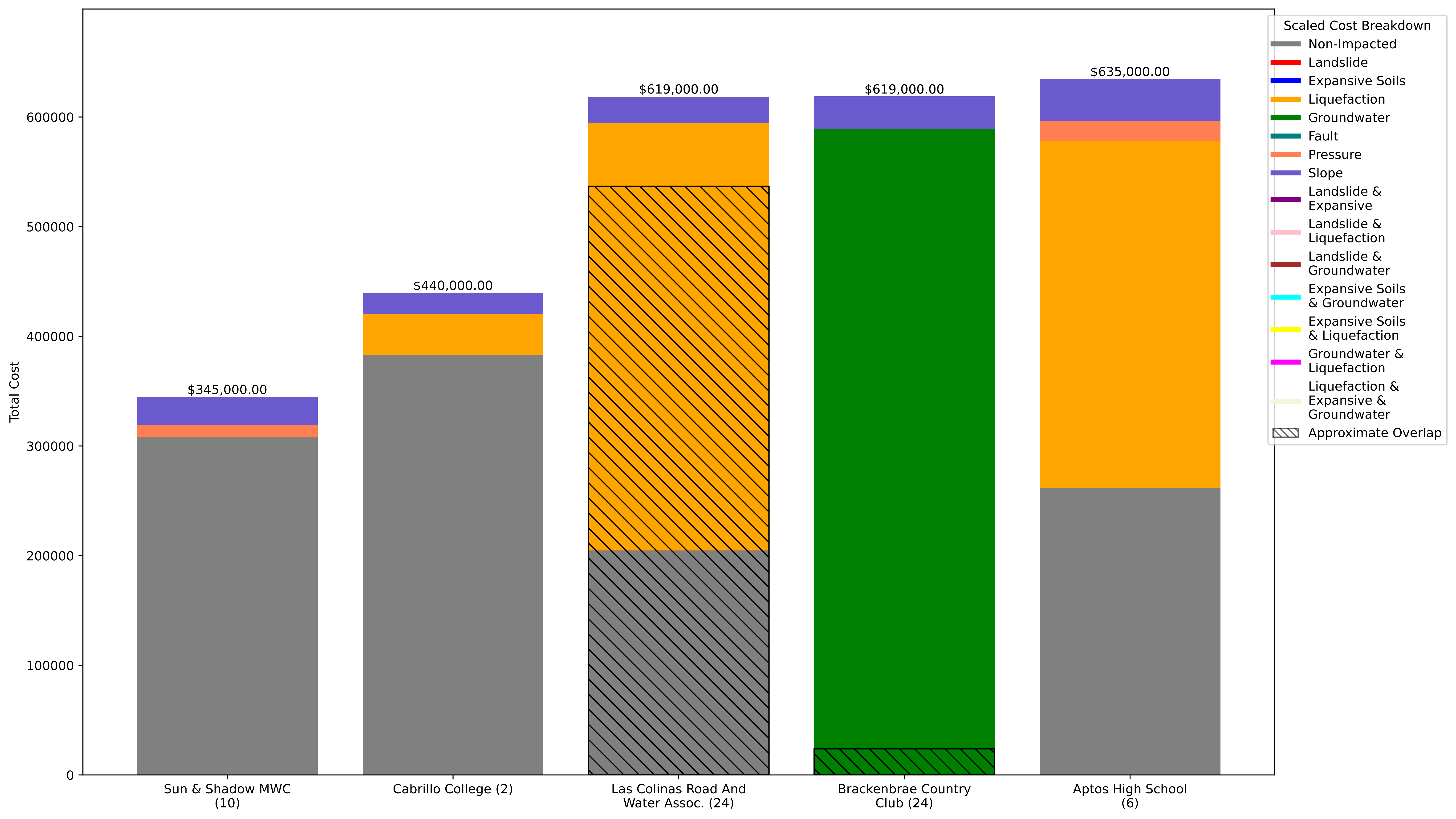
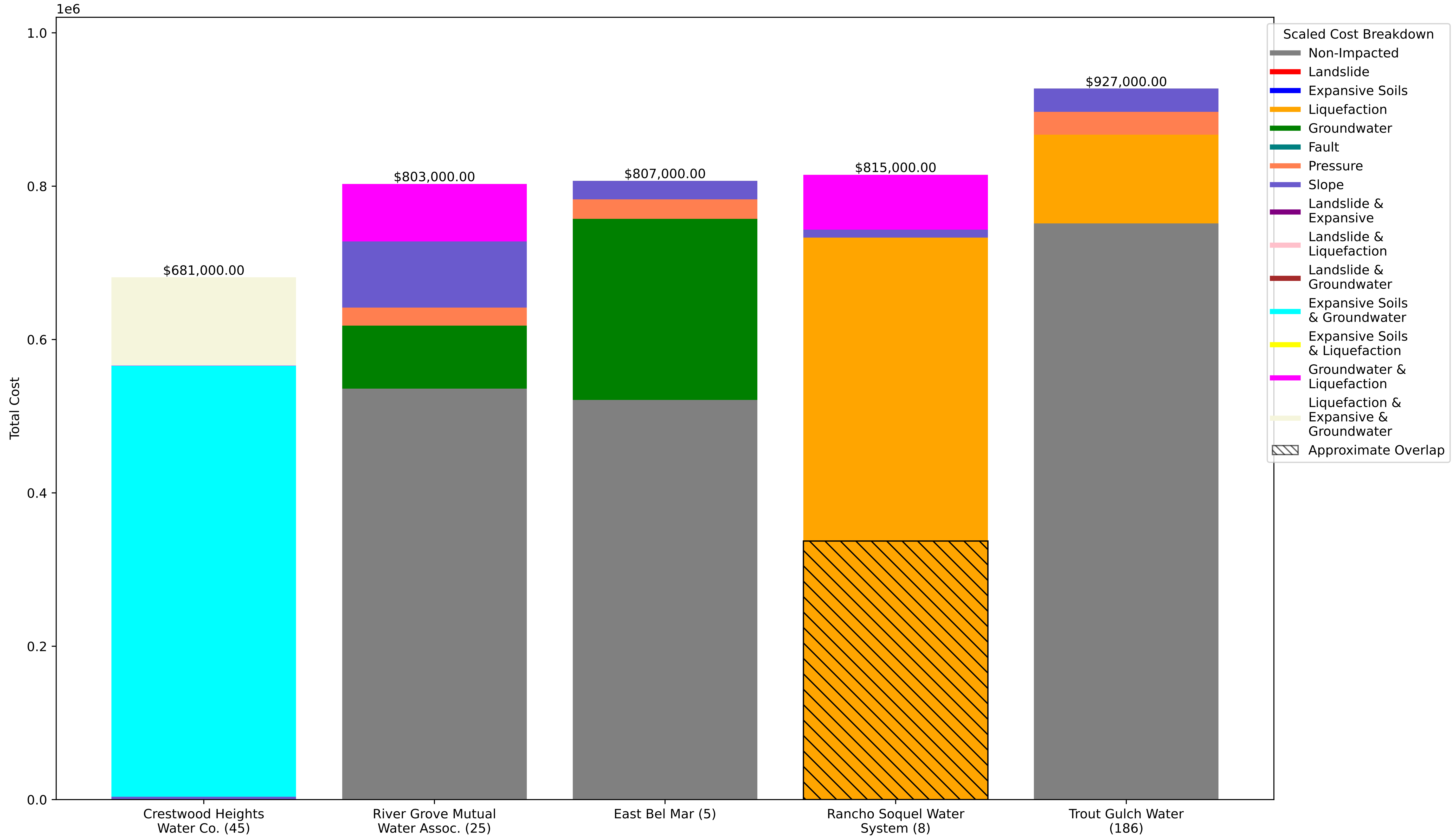
25000
50000
75000
100000
125000
150000
175000
$23,000.00
$31,000.00
$86,000.00
$175,000.00
$178,000.00
Forest Springs (126)
Vista Robles Assoc. (19)
Moon Meadows (7)
Allan Lane Water Assoc. (17)
Renaissance High (2)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap


Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap
Total Cost
350000
300000
250000
200000
150000
100000
50000
0
$194,000.00
$229,000.00
$232,000.00
$234,000.00
$330,000.00
Quail Hollow Circle (8)
Zayante Acres (14)
JB Ranch (6)
Pine Tree Lane MWC (36)
Santa Cruz Waldorf School (1)



Total Cost
0
100000
200000
300000
400000
500000
600000
$345,000.00
$440,000.00
$619,000.00
$619,000.00
$635,000.00
Sun & Shadow MWC (10)
Cabrillo College (2)
Las Colinas Road And Water Assoc. (24)
Brackenbrae Country Club (24)
Aptos High School (6)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap



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0.8
0.6
0.4
0.2
0.0
Total Cost
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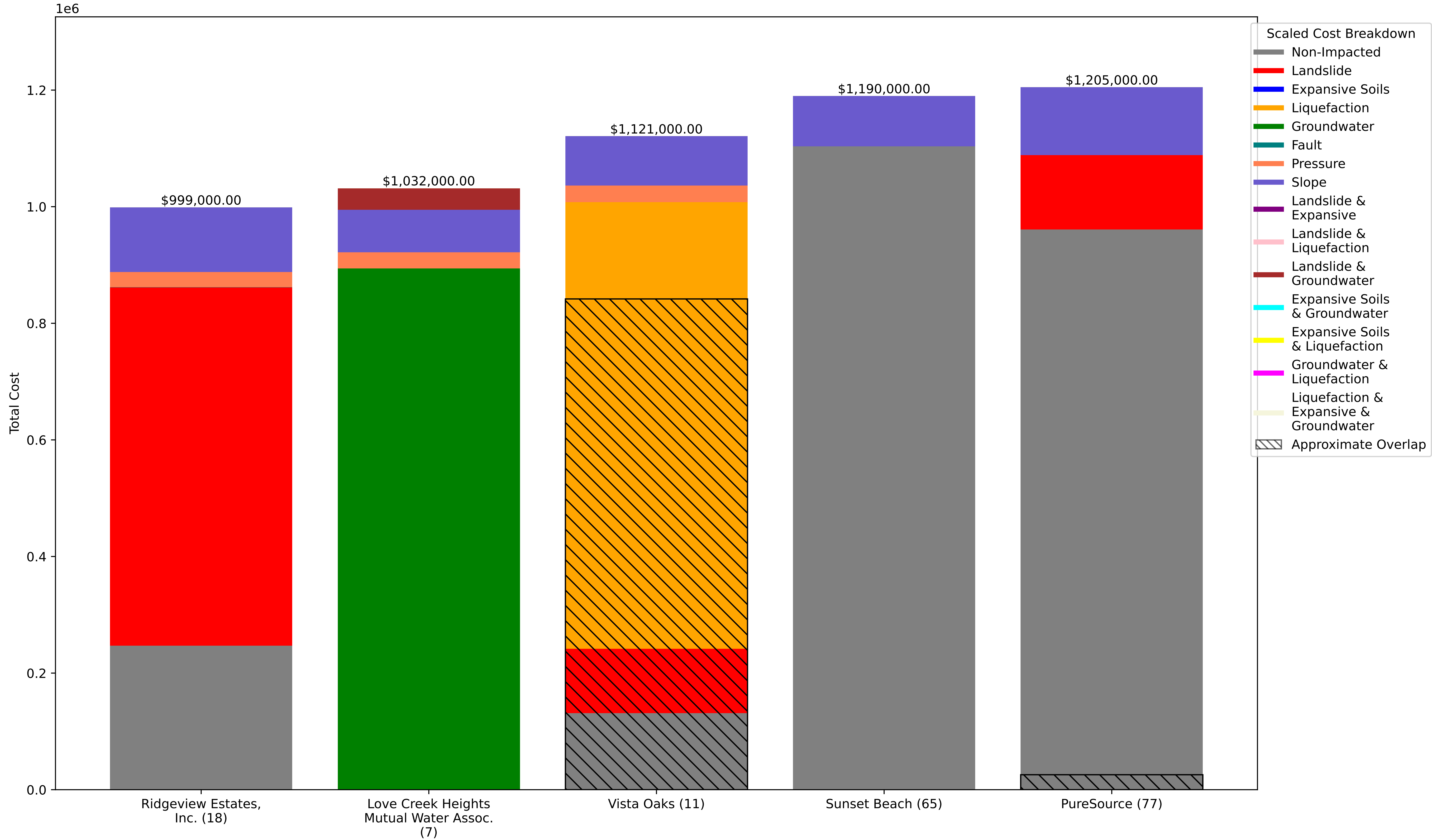
$803,000.00
$807,000.00
$815,000.00
$927,000.00
Crestwood Heights Water Co. (45)
River Grove Mutual Water Assoc. (25)
East Bel Mar (5)
Rancho Soquel Water System (8)
Trout Gulch Water (186)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap



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Total Cost
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$1,205,000.00
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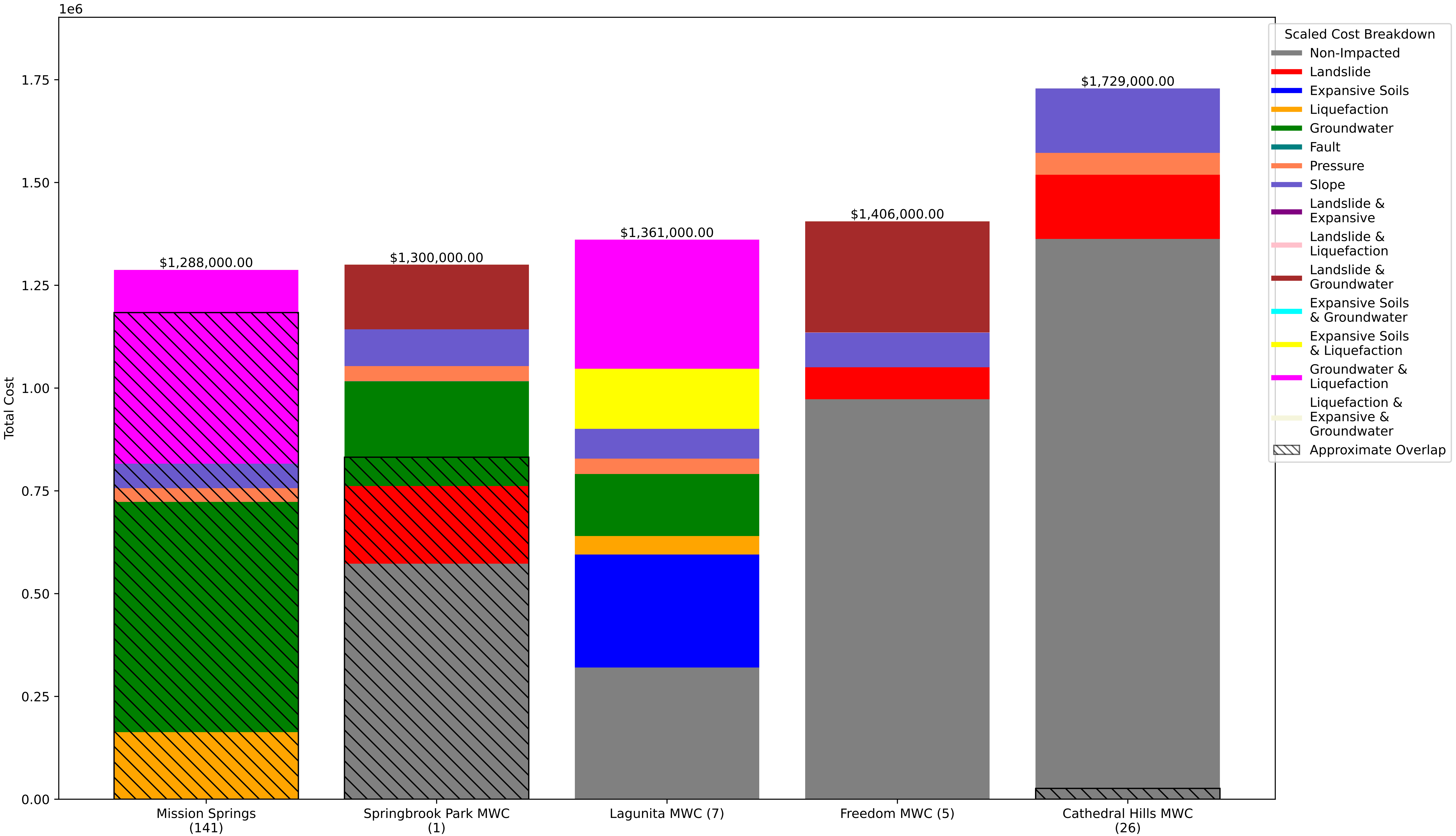
Love Creek Heights Mutual Water Assoc. (7)
Vista Oaks (11)
Sunset Beach (65)
PureSource (77)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap



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0.75
1.00
1.25
1.50
1.75
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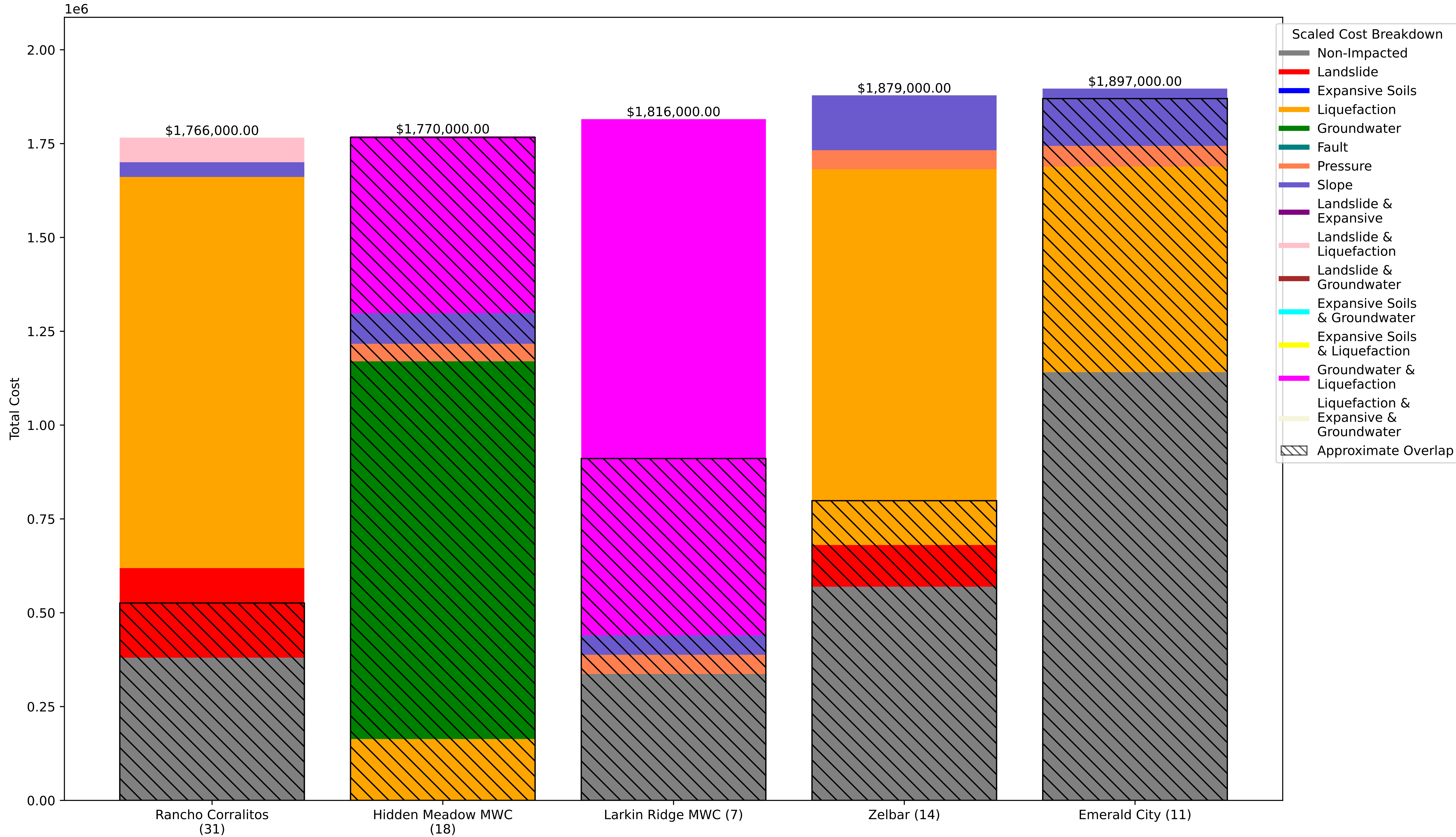
$1,300,000.00
$1,361,000.00
$1,406,000.00
$1,729,000.00
Mission Springs (141)
Springbrook Park MWC (1)
Lagunita MWC (7)
Freedom MWC (5)
Cathedral Hills MWC (26)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap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1.50
1.25
1.00
0.75
0.50
0.25
0.00
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$1,770,000.00
$1,816,000.00
$1,879,000.00
$1,897,000.00
Rancho Corralitos (31)
Hidden Meadow MWC (18)
Larkin Ridge MWC (7)
Zelbar (14)
Emerald City (11)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
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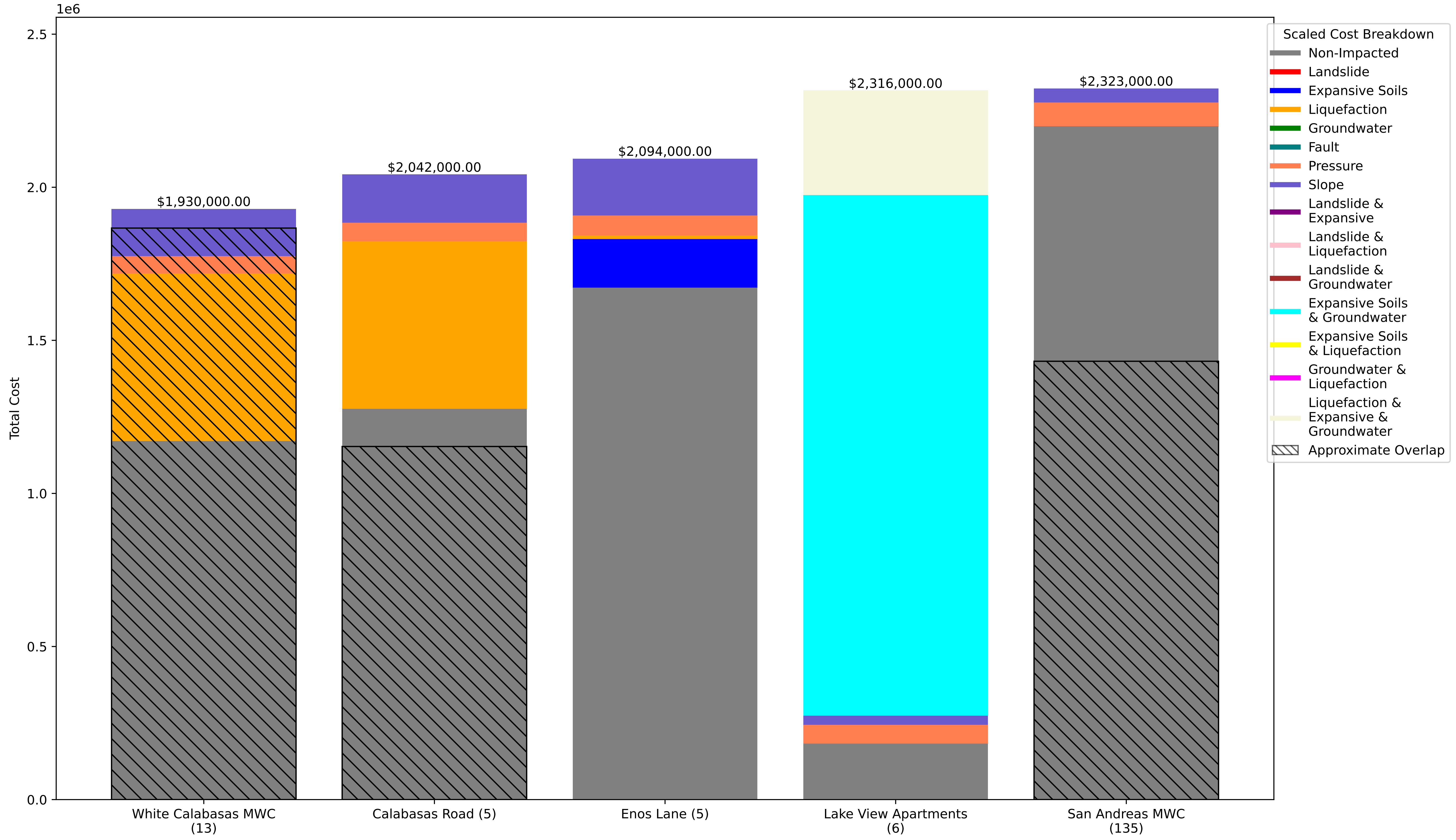
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap



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1.5
1.0
0.5
0.0
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$2,316,000.00
$2,323,000.00
White Calabasas MWC (13)
Calabasas Road (5)
Enos Lane (5)
Lake View Apartments (6)
San Andreas MWC (135)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
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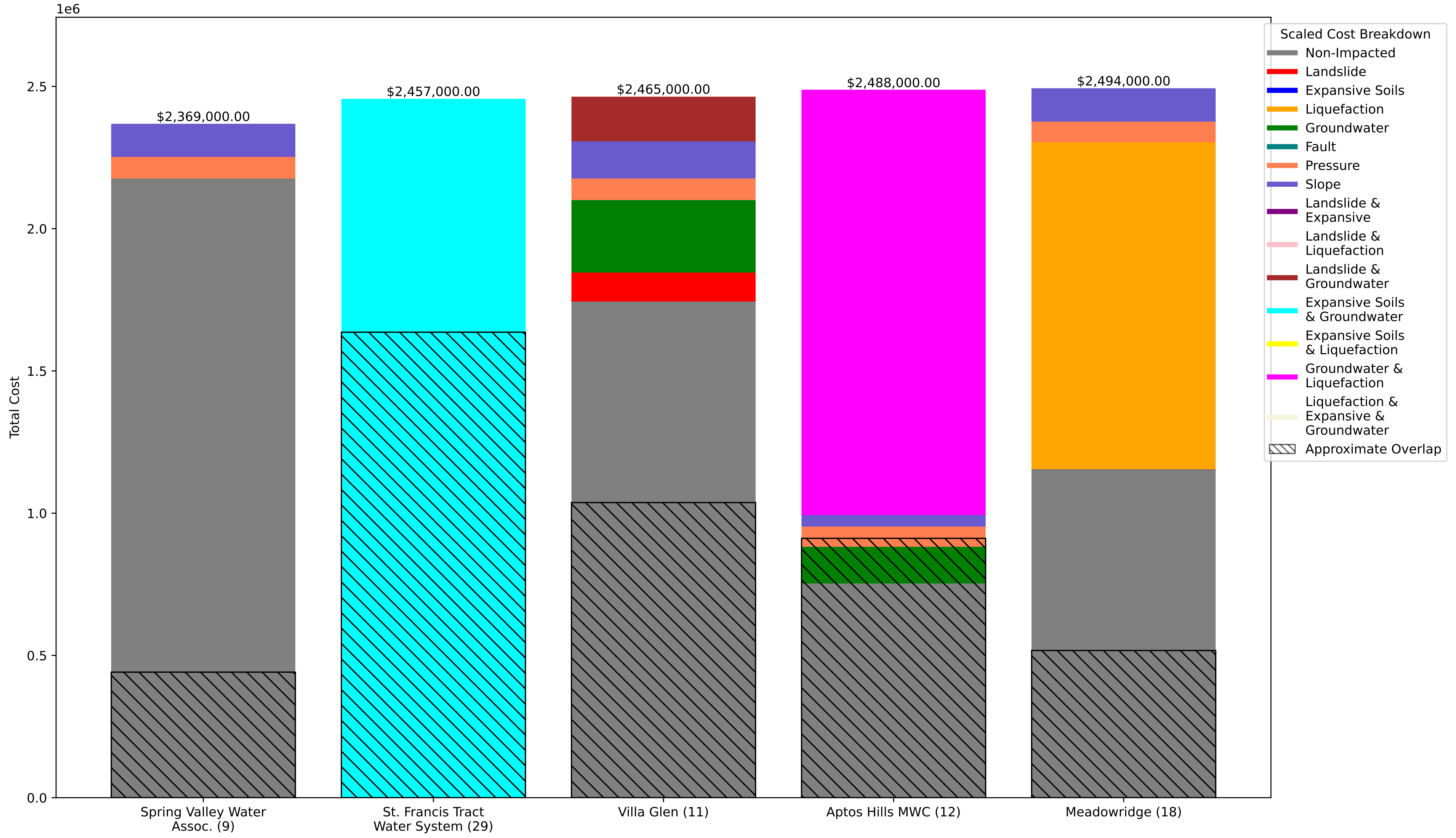
Approximate Overlap



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0.5
0.0
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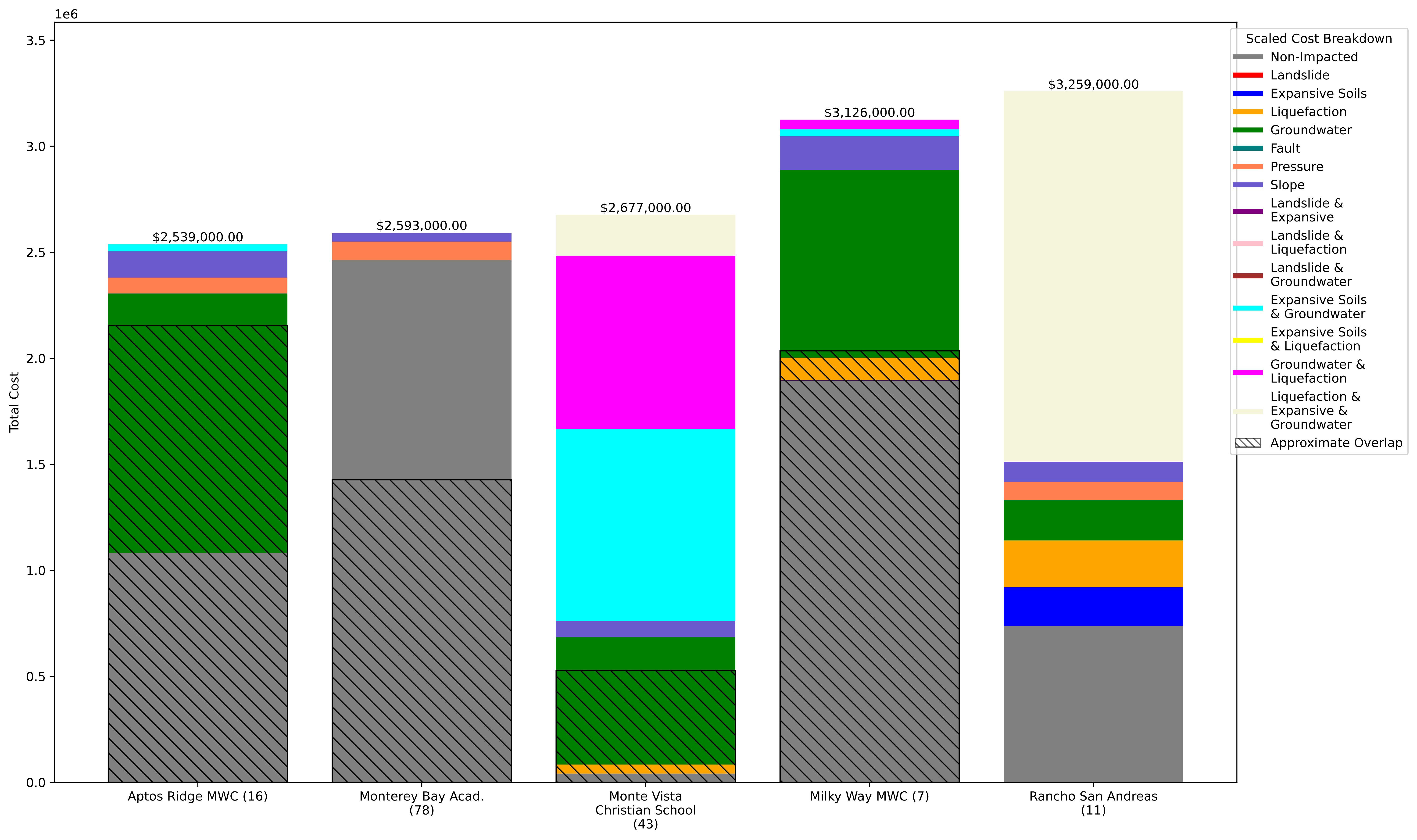
$2,494,000.00
Spring Valley Water Assoc. (9)
St. Francis Tract Water System (29)
Villa Glen (11)
Aptos Hills MWC (12)
Meadowridge (18)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap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2.5
2.0
1.5
1.0
0.5
0.0
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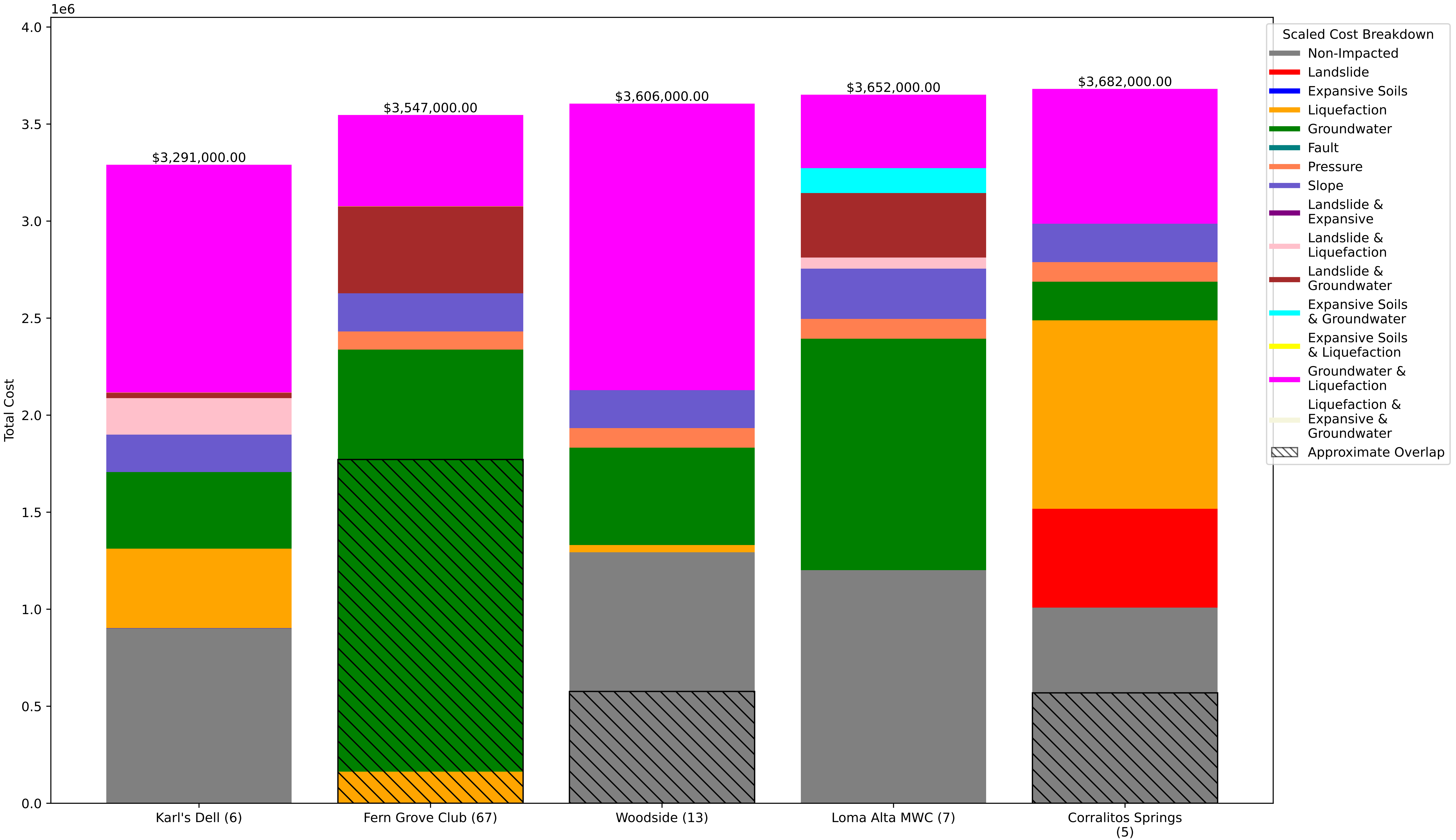
$2,593,000.00
$2,677,000.00
$3,126,000.00
$3,259,000.00
Aptos Ridge MWC (16)
Monterey Bay Acad. (78)
Monte Vista Christian School (43)
Milky Way MWC (7)
Rancho San Andreas (11)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap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3.0
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1.0
0.5
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$3,606,000.00
$3,652,000.00
$3,682,000.00
Karl's Dell (6)
Fern Grove Club (67)
Woodside (13)
Loma Alta MWC (7)
Corralitos Springs (5)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
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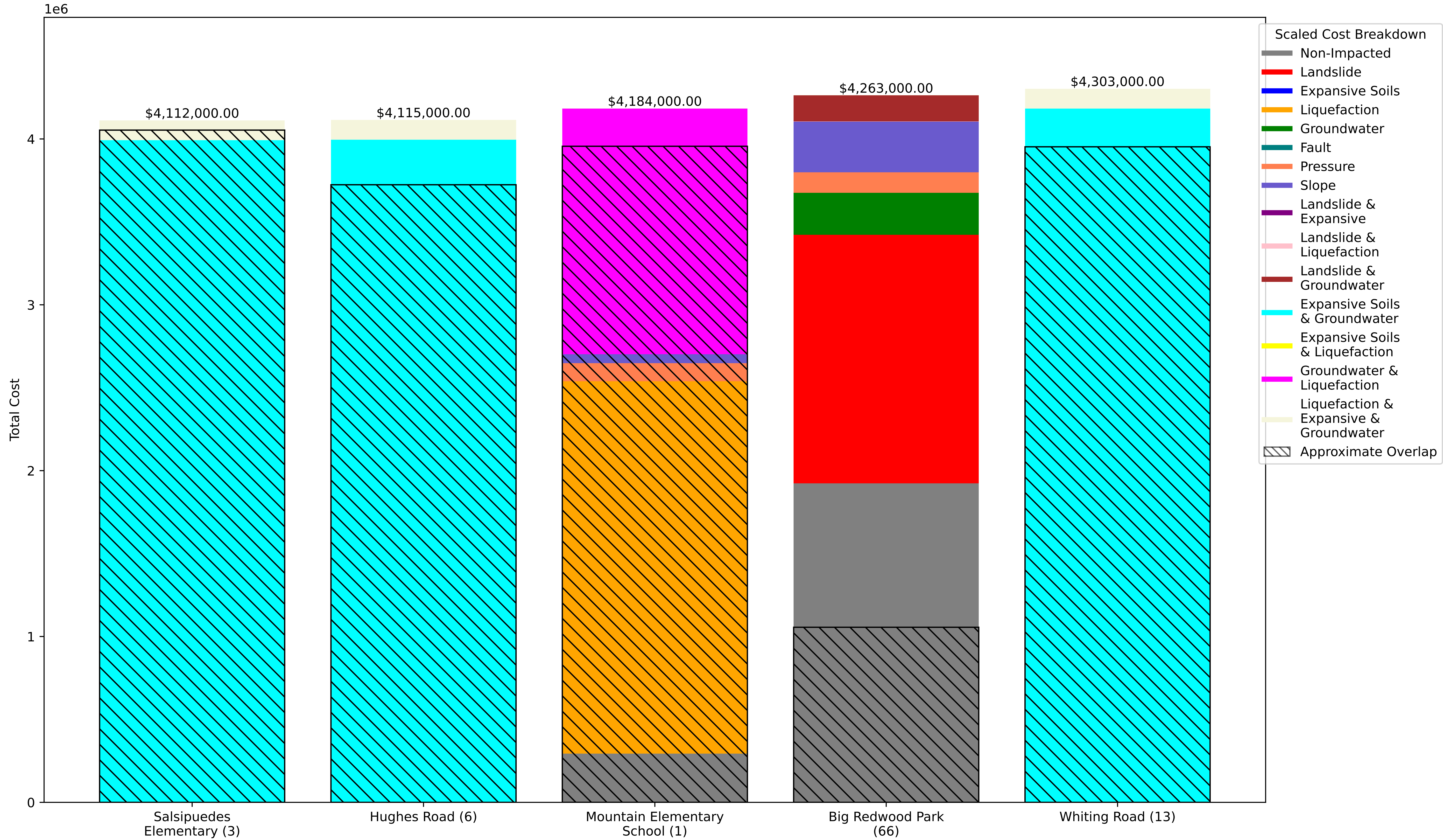
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap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Total Cost
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1
2
3
4
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$4,115,000.00
$4,184,000.00
$4,263,000.00
$4,303,000.00
Salsipuedes Elementary (3)
Hughes Road (6)
Mountain Elementary School (1)
Big Redwood Park (66)
Whiting Road (13)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
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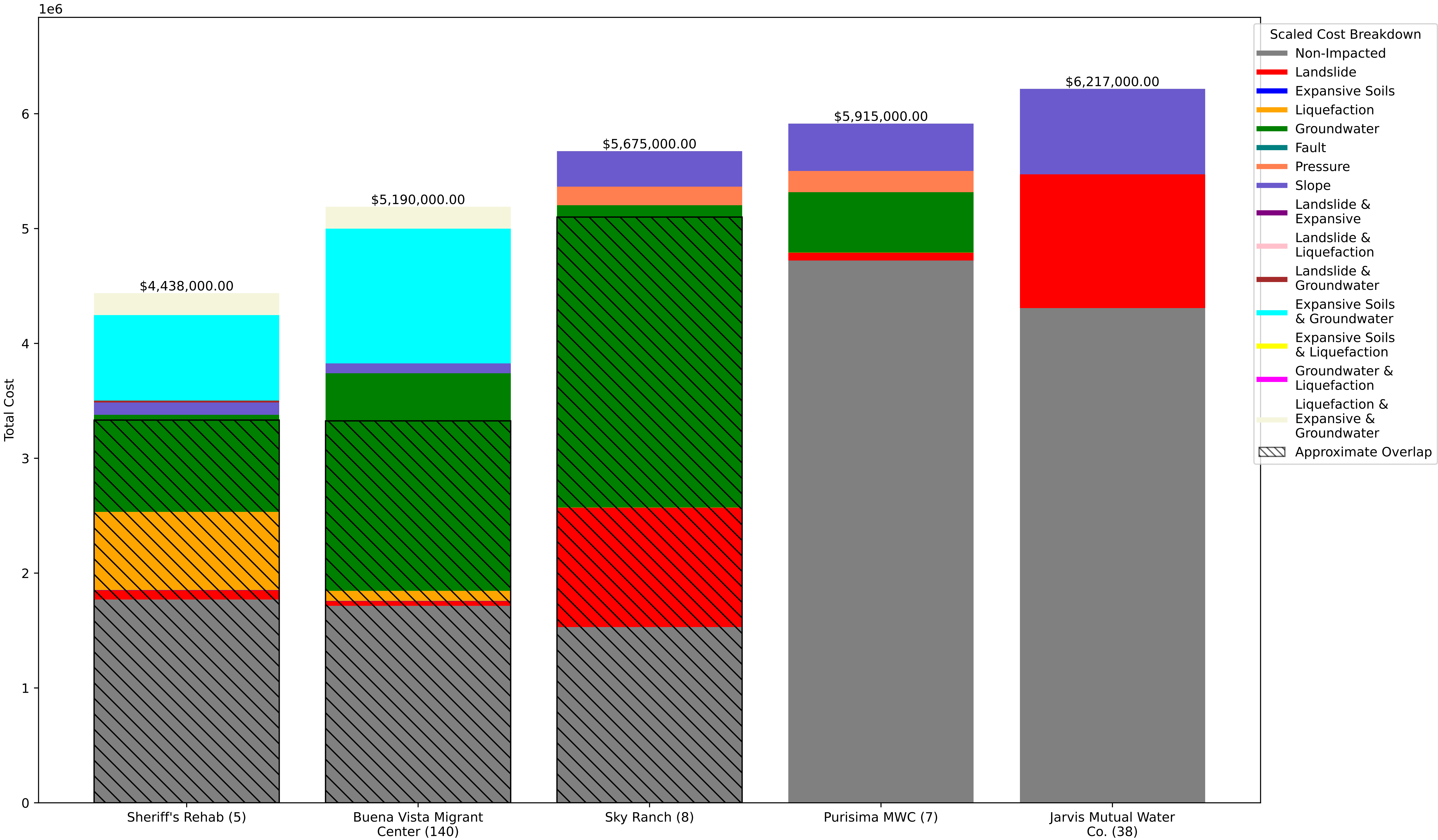
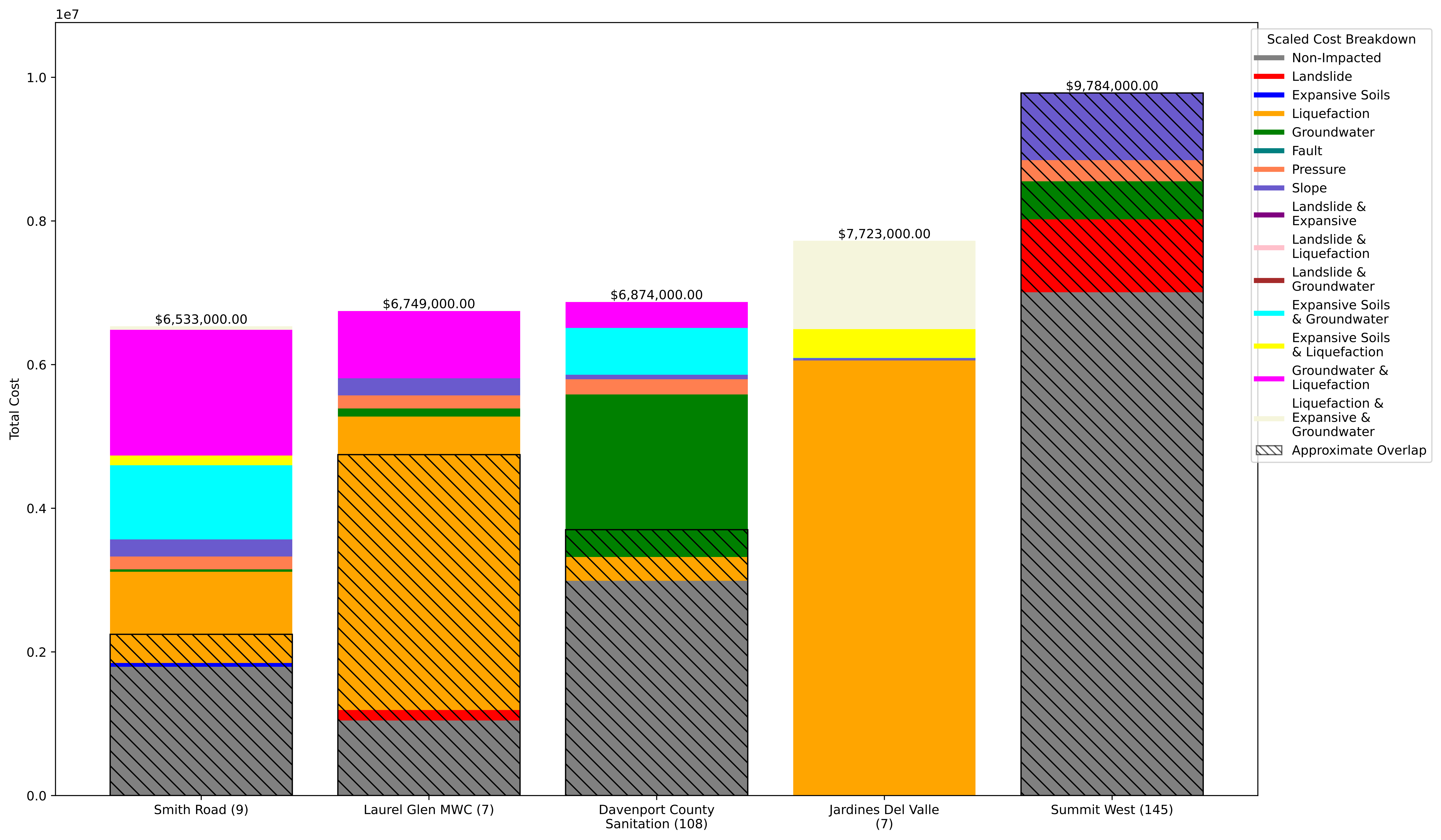
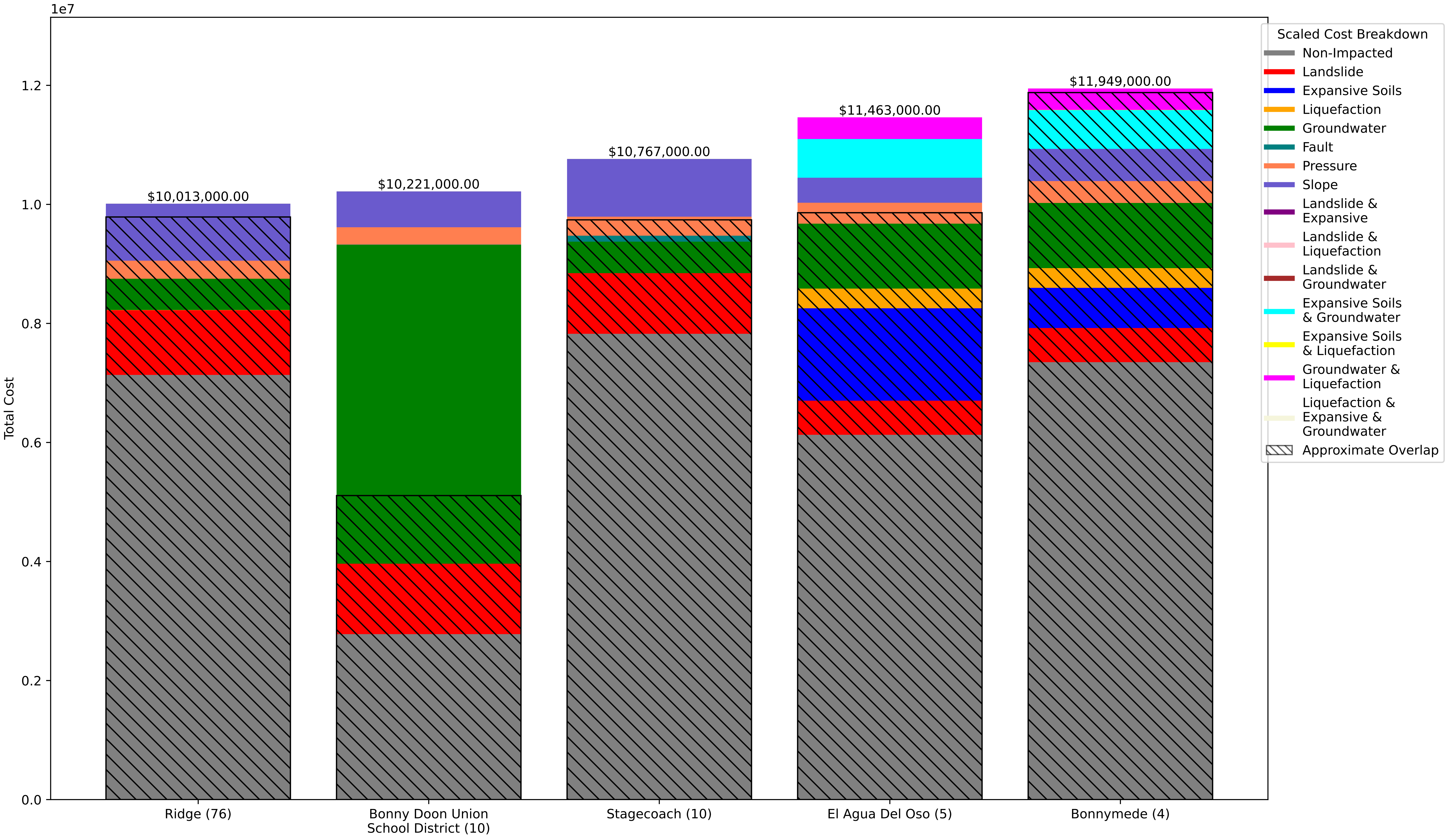
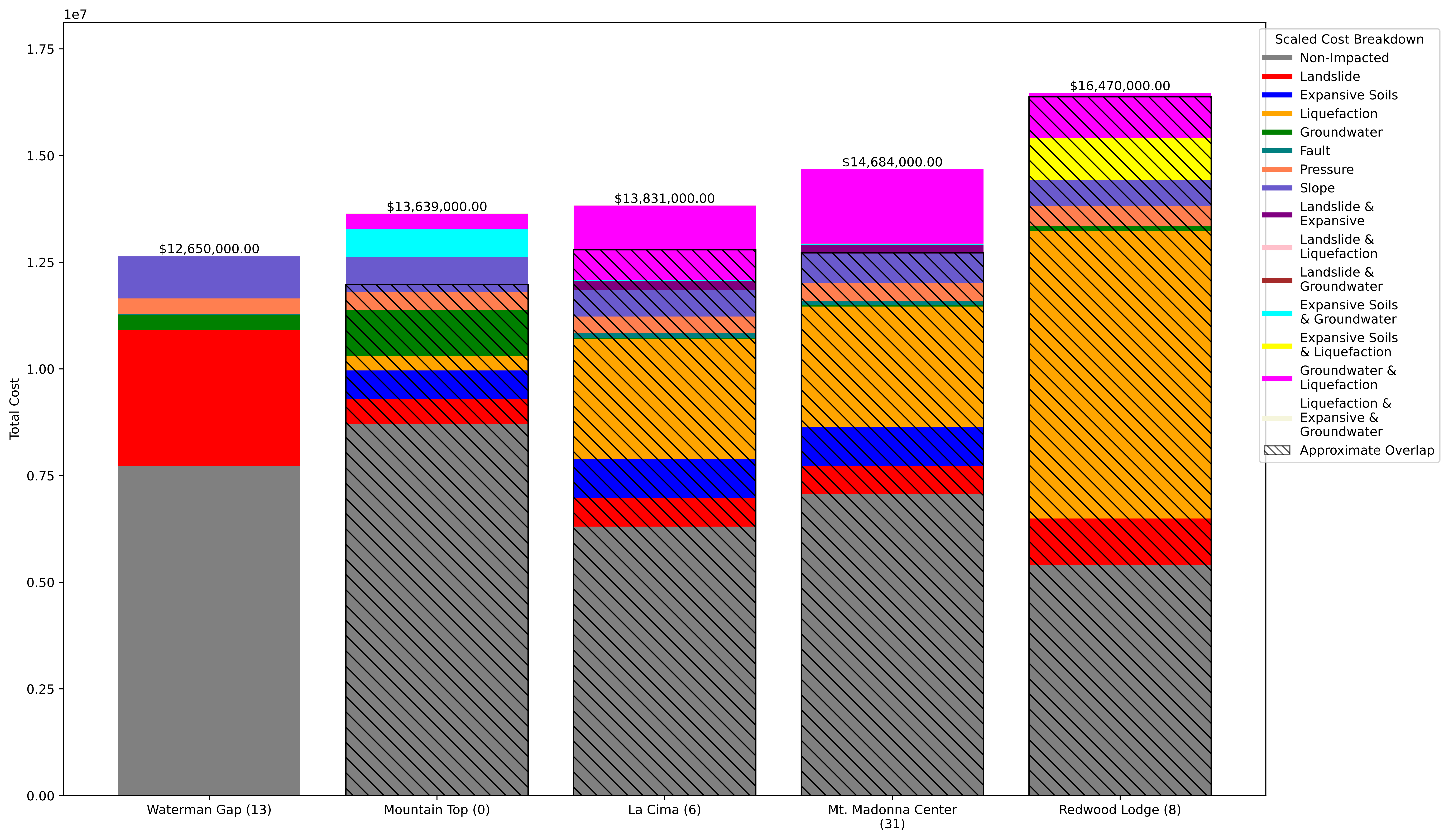
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap


1e6
Total Cost
0
1
2
3
4
5
6
$4,438,000.00
$5,190,000.00
$5,675,000.00
$5,915,000.00
$6,217,000.00
Sheriff's Rehab (5)
Buena Vista Migrant Center (140)
Sky Ranch (8)
Purisima MWC (7)
Jarvis Mutual Water Co. (38)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap

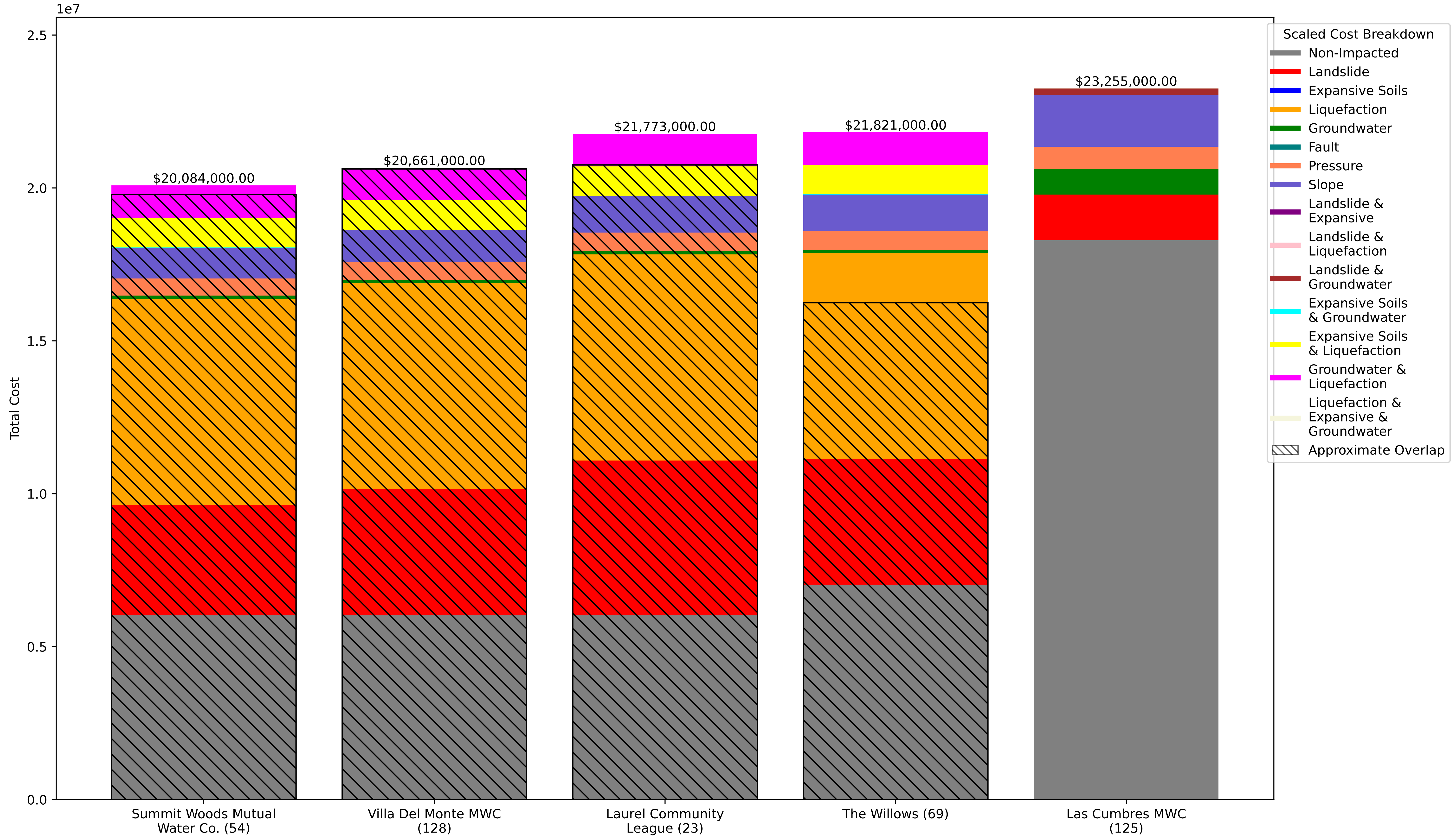


1e7
Total Cost
0.0
0.2
0.4
0.6
0.8
1.0
$6,533,000.00
$6,749,000.00
$6,874,000.00
$7,723,000.00
$9,784,000.00
Smith Road (9)
Laurel Glen MWC (7)
Davenport County Sanitation (108)
Jardines Del Valle (7)
Summit West (145)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap


1e7
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Total Cost
$10,013,000.00
$10,221,000.00
$10,767,000.00
$11,463,000.00
$11,949,000.00
Ridge (76)
Bonny Doon Union School District (10)
Stagecoach (10)
El Agua Del Oso (5)
Bonnymede (4)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap

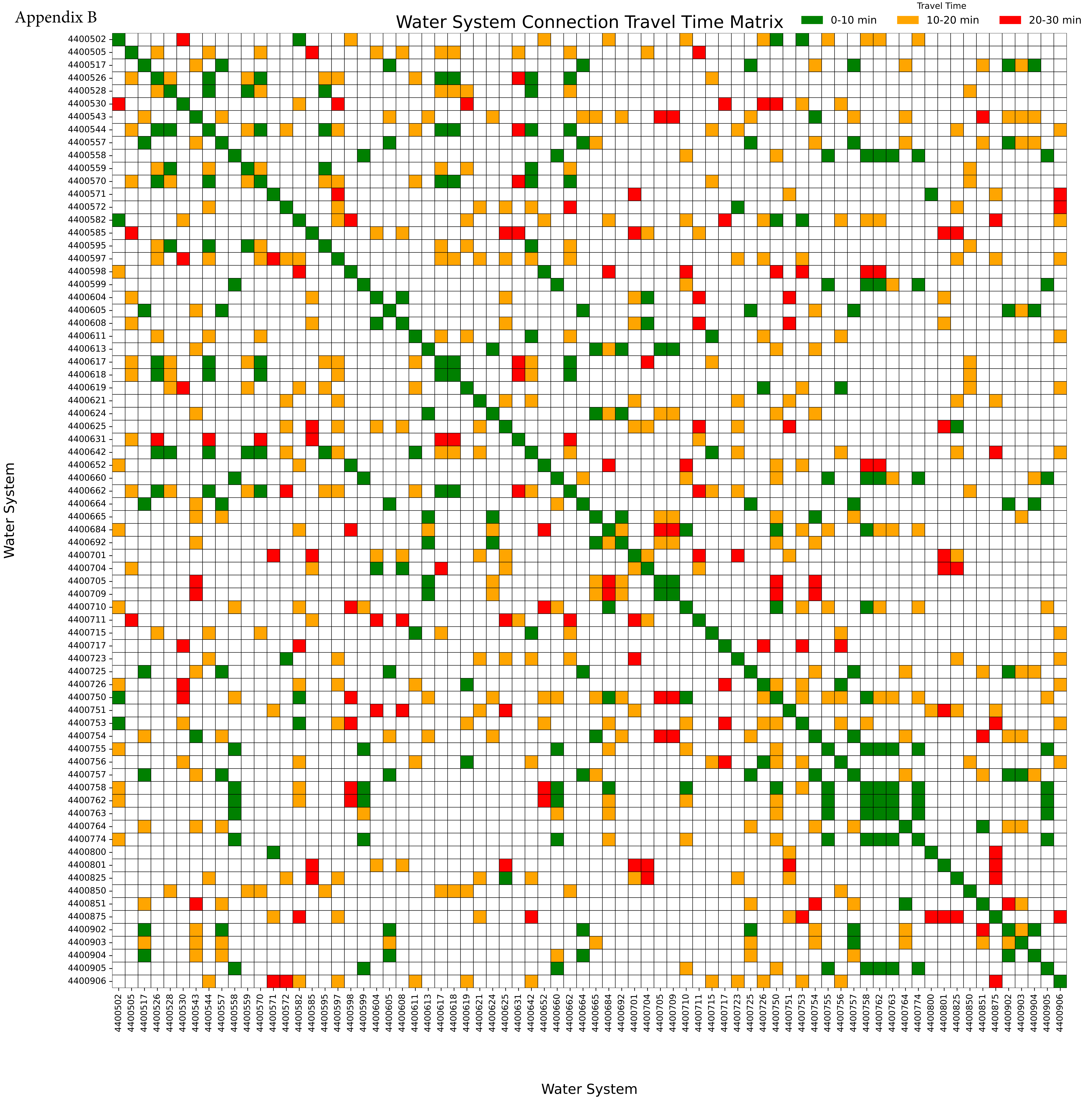


1e7
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Total Cost
$12,650,000.00
$13,639,000.00
$13,831,000.00
$14,684,000.00
$16,470,000.00
Waterman Gap (13)
Mountain Top (0)
La Cima (6)
Mt. Madonna Center (31)
Redwood Lodge (8)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap



1e7
Total Cost
2.5
2.0
1.5
1.0
0.5
0.0
$20,084,000.00
$20,661,000.00
$21,773,000.00
$21,821,000.00
$23,255,000.00
Summit Woods Mutual Water Co. (54)
Villa Del Monte MWC (128)
Laurel Community League (23)
The Willows (69)
Las Cumbres MWC (125)
Scaled Cost Breakdown
Non-Impacted
Landslide
Expansive Soils
Liquefaction
Groundwater
Fault
Pressure
Slope
Landslide & Expansive
Landslide & Liquefaction
Landslide & Groundwater
Expansive Soils & Groundwater
Expansive Soils & Liquefaction
Groundwater & Liquefaction
Liquefaction & Expansive & Groundwater
Approximate Overlap

Appendix B



Water System Connection Travel Time Matrix
Travel Time
0-10 min
10-20 min
20-30 min
Water System
Water System
4400502
4400505
4400517
4400526
4400528
4400530
4400543
4400544
4400557
4400558
4400559
4400570
4400571
4400572
4400582
4400585
4400595
4400597
4400598
4400599
4400604
4400605
4400608
4400611
4400613
4400617
4400618
4400619
4400621
4400624
4400625
4400631
4400642
4400652
4400660
4400662
4400664
4400665
4400684
4400692
4400701
4400704
4400705
4400709
4400710
4400711
4400715
4400717
4400723
4400725
4400726
4400750
4400751
4400753
4400754
4400755
4400756
4400757
4400758
4400762
4400763
4400764
4400774
4400800
4400801
4400825
4400850
4400851
4400875
4400902
4400903
4400904
4400905
4400906

```python
import arcpy
import matplotlib.pyplot as plt
import os
import numpy as np
import textwrap
import locale
import matplotlib.patches as mpatches


locale.setlocale(locale.LC_ALL, '')

arcpy.env.workspace = r"C:\GIS\Connection_Feasibilities\Connection_Feasibilities.gdb"
feature_class = "CFRoutes1ii7qtw"

# output directory for pdf plots
output_directory = r"C:\GIS\Connection_Feasibilities\pdfs\plots"
if not os.path.exists(output_directory):
    os.makedirs(output_directory)

# chart dimensions and layout
charts_per_page = 5
paper_width = 17
paper_height = 11

# create list for plot data
plot_data = []

# Cost factors
base_cost = 310
landslide_factor = 1.25
expansive_soils_factor = 1.15
liquefaction_factor = 1.30
groundwater_factor = 1.20
double_overlap_factor = 1.10
triple_overlap_factor = 1.20

# wrap long labels into multiple lines
def wrap_label(label, width=15):
    return "\n".join(textwrap.wrap(label, width))

# chart colors for each cost
cost_colors = {
    'non_impacted_cost': 'grey',
    'landslide_cost': 'red',
    'expansive_cost': 'blue',
    'liquefaction_cost': 'orange',
    'groundwater_cost': 'green',
    'fault_cost': 'teal',
```

```
    'pressure_cost': '#FF7F50',
    'slope_cost': '#6A5ACD',
    'ls_exp_cost': 'purple',
    'ls_liq_cost': 'pink',
    'ls_gw_cost': 'brown',
    'exp_gw_cost': 'cyan',
    'exp_liq_cost': 'yellow',
    'gw_liq_cost': 'magenta',
    'triple_cost': 'beige',

}
# legend labels
custom_labels = {
    'non_impacted_cost': 'Non-Impacted',
    'landslide_cost': 'Landslide',
    'expansive_cost': 'Expansive Soils',
    'liquefaction_cost': 'Liquefaction',
    'groundwater_cost': 'Groundwater',
    'fault_cost': 'Fault',
    'pressure_cost': 'Pressure',
    'slope_cost': 'Slope',
    'ls_exp_cost': 'Landslide & Expansive',
    'ls_liq_cost': 'Landslide & Liquefaction',
    'ls_gw_cost': 'Landslide & Groundwater',
    'exp_gw_cost': 'Expansive Soils & Groundwater',
    'exp_liq_cost': 'Expansive Soils & Liquefaction',
    'gw_liq_cost': 'Groundwater & Liquefaction',
    'triple_cost': 'Liquefaction & Expansive & Groundwater',
}

# find the maximum slope value
max_slope = 0
with arcpy.da.SearchCursor(feature_class, ["slope_degrees_path"]) as cursor:
    for row in cursor:
        slope = row[0]
        if slope is not None and slope > max_slope:
            max_slope = slope

print(f"Max slope value found: {max_slope}")

# create an update cursor
with arcpy.da.UpdateCursor(feature_class, [
    "shape_length_linear", "Landslide_crossing_ft", "epansive_crossing_ft",
    "liquefaction_crossing_ft", "gw_crossing_ft", "ls_exp", "ls_liq",
    "ls_gw", "exp_gw", "exp_liq", "gw_liq", "liq_exp_gw", "total_cost",
    "non_impacted_length", "total_impacted_length", "System_Name", "FacilityID",
    "FacilityRank", "IncidentCurbApproach", "FacilityCurbApproach", "IncidentID",
    "StartTime", "EndTime", "Total_Minutes","service_connections_count", "state_fault_cross",
"percent_overlap", "source_to_sink_elev", "slope_degrees_path"]) as cursor:

```

```
    record_count = 0  # initialize counter to keep track of records


    for row in cursor:

        total_length = row[0]
        landslide_length = row[1] or 0
        expansive_length = row[2] or 0
        liquefaction_length = row[3] or 0
        groundwater_length = row[4] or 0
        ls_exp_length = row[5] or 0
        ls_liq_length = row[6] or 0
        ls_gw_length = row[7] or 0
        exp_gw_length = row[8] or 0
        exp_liq_length = row[9] or 0
        gw_liq_length = row[10] or 0
        liq_exp_gw_length = row[11]  # Triple overlap length
        record_name = row[15]
        num_connections = row[24]
        fault = row[25]
        overlap = row[26]
        pressure = row[27]
        slope = row[28]


        # calc to adjust single impacted lengths
        adjusted_landslide_length = landslide_length - (ls_exp_length + ls_liq_length + ls_gw_length)
        adjusted_liquefaction_length = liquefaction_length - (exp_liq_length + gw_liq_length + ls_liq_length) + (liq_exp_gw_length or 0)
        adjusted_expansive_length = expansive_length - (exp_liq_length + exp_gw_length + ls_exp_length) + (liq_exp_gw_length or 0)
        adjusted_groundwater_length = groundwater_length - (gw_liq_length + exp_gw_length + ls_gw_length) + (liq_exp_gw_length or 0)

        # calc to adjust double impacted lengths
        #landslide triple overlap scenario doesn't exist in the county so no need to substract triple overalp sections
        adjusted_double_ls_exp_length = ls_exp_length
        adjusted_double_ls_liq_length = ls_liq_length
        adjusted_double_ls_gw_length = ls_gw_length
        adjusted_double_exp_gw_length = exp_gw_length - (liq_exp_gw_length or 0)
        adjusted_double_exp_liq_length = exp_liq_length - (liq_exp_gw_length or 0)
        adjusted_double_gw_liq_length = gw_liq_length - (liq_exp_gw_length or 0)

        # calc to adjust triple impacted lengths
        triple_length = liq_exp_gw_length or 0 # always equals triple

        # calc the length that is not impacted
        unimpacted_length = total_length - adjusted_landslide_length -  adjusted_liquefaction_length - adjusted_expansive_length - adjusted_groundwater_length - adjusted_double_ls_e-
```

```
xp_length - adjusted_double_ls_liq_length - adjusted_double_ls_gw_length - adjusted_double_exp_gw_length - adjusted_double_exp_liq_length - adjusted_double_gw_liq_length - triple_length

        # Calculate costs:

        #unimpacted costs
        non_impacted_cost = unimpacted_length * base_cost

        #single costs
        landslide_cost = adjusted_landslide_length * base_cost * landslide_factor
        expansive_cost = adjusted_expansive_length * base_cost * expansive_soils_factor
        liquefaction_cost = adjusted_liquefaction_length * base_cost * liquefaction_factor
        groundwater_cost = adjusted_groundwater_length * base_cost * groundwater_factor

        #double costs
        ls_exp_cost = adjusted_double_ls_exp_length * ((landslide_factor + expansive_soils_factor)/2) * double_overlap_factor * base_cost
        ls_liq_cost = adjusted_double_ls_liq_length * ((landslide_factor + liquefaction_factor)/2) * double_overlap_factor * base_cost
        ls_gw_cost = adjusted_double_ls_gw_length * ((landslide_factor + groundwater_factor)/2) * double_overlap_factor * base_cost
        exp_gw_cost = adjusted_double_exp_gw_length * ((expansive_soils_factor + groundwater_factor)/2) * double_overlap_factor * base_cost
        exp_liq_cost = adjusted_double_exp_liq_length * ((liquefaction_factor + expansive_soils_factor)/2) * double_overlap_factor * base_cost
        gw_liq_cost = adjusted_double_gw_liq_length * ((liquefaction_factor + groundwater_factor)/2) * double_overlap_factor * base_cost

        # only triple cost scenario are these 3 criteria
        triple_cost = triple_length * ((liquefaction_factor + expansive_soils_factor + groundwater_factor)/3) * triple_overlap_factor * base_cost


        # calc total cost
        total_cost = non_impacted_cost + landslide_cost + expansive_cost + liquefaction_cost + groundwater_cost + ls_exp_cost + ls_liq_cost + ls_gw_cost + exp_gw_cost + exp_liq_cost + gw_liq_cost + triple_cost

        pressure_cost = 0
        if pressure > 50:
            pressure_cost += total_length * 220 * .05
            total_cost += pressure_cost


        # Add 100k if pipe crosses an active fault trace
        print(fault)
        fault_cost = 0
        if fault == "Yes":
            fault_cost = 100000
            total_cost += 100000
```

```python

        # calc slope factor relative to the max slope
        slope_factor = 1.0
        if max_slope > 0:  # Avoid division by zero
            slope_factor = 1 + (((slope - 1.0) / (max_slope - 1.0)) * (1.15 - 1.0))

        # calc slope cost
        slope_cost = (total_length * base_cost * slope_factor) - (total_length * base_cost)
        #print(f"  Total before slope Cost: {locale.currency(total_cost, grouping=True)}")
        total_cost += slope_cost
        #print(f"  Total after slope Cost: {locale.currency(total_cost, grouping=True)}")

        # print slope-related information for each record
        #print(f"Record {record_count + 1} ({record_name}):")
        #print(f"  Slope: {slope} degrees")
        #print(f"  Slope Factor: {slope_factor}")




        # Print out the costs for this record
        # print(f"Record {record_count + 1} ({record_name}):")
        # print(f"  Non-Impacted Cost: {locale.currency(non_impacted_cost, grouping=True)}")
        # print(f"  Landslide Cost: {locale.currency(landslide_cost, grouping=True)}")
        # print(f"  Expansive Soil Cost: {locale.currency(expansive_cost, grouping=True)}")
        # print(f"  Liquefaction Cost: {locale.currency(liquefaction_cost, grouping=True)}")
        # print(f"  Groundwater Cost: {locale.currency(groundwater_cost, grouping=True)}")
        # print(f"  Fault: {locale.currency(fault_cost, grouping=True)}")
        # print(f"  Pressure: {locale.currency(pressure_cost, grouping=True)}")
        # print(f"  Slope Cost: {locale.currency(slope_cost, grouping=True)}")
        # print(f"  Landslide + Expansive Soil Cost: {locale.currency(ls_exp_cost, grouping=True)}")
        # print(f"  Landslide + Liquefaction Cost: {locale.currency(ls_liq_cost, grouping=True)}")
        # print(f"  Landslide + Groundwater Cost: {locale.currency(ls_gw_cost, grouping=True)}")
        # print(f"  Expansive Soil + Groundwater Cost: {locale.currency(exp_gw_cost, grouping=True)}")
        # print(f"  Expansive Soil + Liquefaction Cost: {locale.currency(exp_liq_cost, grouping=True)}")
        # print(f"  Groundwater + Liquefaction Cost: {locale.currency(gw_liq_cost, grouping=True)}")
        # print(f"  Triple Overlap Cost: {locale.currency(triple_cost, grouping=True)}")
        # print(f"  Total Cost: {locale.currency(total_cost, grouping=True)}\n")

        # store new records into active attribute table
        row[12] = total_cost
        row[13] = unimpacted_length
        row[14] = total_length - unimpacted_length
        cursor.updateRow(row)

```

```
        # Plot the the data
        # Add the record and its cost breakdown to plot data
        plot_data.append({
            'record_name': record_name,
            'num_connections': num_connections,
            'total_cost': total_cost,
            'overlap': overlap,
            'costs': {
                'non_impacted_cost': non_impacted_cost,
                'landslide_cost': landslide_cost,
                'expansive_cost': expansive_cost,
                'liquefaction_cost': liquefaction_cost,
                'groundwater_cost': groundwater_cost,
                'fault_cost': fault_cost,
                'slope_cost': slope_cost,
                'pressure_cost': pressure_cost,
                'ls_exp_cost': ls_exp_cost,
                'ls_liq_cost': ls_liq_cost,
                'ls_gw_cost': ls_gw_cost,
                'exp_gw_cost': exp_gw_cost,
                'exp_liq_cost': exp_liq_cost,
                'gw_liq_cost': gw_liq_cost,
                'triple_cost': triple_cost
            }
        })

plot_data.sort(key=lambda x: x['total_cost'])

# Total number of records
total_records = len(plot_data)

#calc the total number of pages needed
total_pages = int(np.ceil(total_records / charts_per_page))


# Loop through pages and plot each set consisting of 5 charts
for page_num in range(total_pages):
    fig, ax = plt.subplots(figsize=(paper_width, paper_height))


    start_idx = page_num * charts_per_page
    end_idx = min(start_idx + charts_per_page, total_records)

    # grab page specific data
    page_data = plot_data[start_idx:end_idx]

    #bar positions and heights
    x_labels = [wrap_label(record ['record_name'] + " (" + str(record['num_connections']) + ")", width=20) for record in page_data]
    total_heights = [record['total_cost'] for record in page_data]
```

```


    bottom_positions = np.zeros(len(page_data))

    for cost_type, color in cost_colors.items():
        heights = [record['costs'].get(cost_type, 0) for record in page_data]
        ax.bar(x_labels, heights, bottom=bottom_positions, color=color, label=wrap_label(custom_labels[cost_type]))
        bottom_positions += heights  # Update bottom position for next cost type

    # put total cost on top of bar
    for i, total_cost, in enumerate(total_heights):
        rounded_cost = round(total_cost / 1000) * 1000
        ax.text(i, rounded_cost, f'{locale.currency(rounded_cost, grouping=True)}', ha='center', va='bottom')

        # hatch height
        hatch_height = page_data[i]['overlap']
        #hatch_height = 0.5 * total_cost

        if hatch_height is None:
            print(f"Warning: 'overlap' value is missing for record {i}. Skipping this bar.")
            continue

        ax.bar(x_labels[i], hatch_height * .01 * total_cost, bottom=0, color='none', edgecolor='black', hatch='\\\\')

    ax.set_ylabel("Total Cost")

    ax.set_xticklabels(x_labels, rotation=0, fontsize=10)

    max_height = max(total_heights) * 1.1
    ax.set_ylim(0, max_height)

    # legend
    a_val = 0.6
    overlap_symbol = mpatches.Patch( facecolor='#FFFFFF', edgecolor = 'black', alpha=0.6,hatch=r'\\\\',label='Approximate Overlap')
    #plt.Line2D([0, 0, 0], [0, .2, .4], color='none', marker='o', markersize=1, label='Overlap', markerfacecolor='black')
    legend_handles = [plt.Line2D([0], [0], color=color, lw=4, label=wrap_label(custom_labels[cost_type])) for cost_type, color in cost_colors.items()]
    legend_handles.append(overlap_symbol)




    legend = ax.legend(handles=legend_handles, loc='upper right', bbox_to_anchor=(1.15, 1))


    legend.set_title("Scaled Cost Breakdown")
```

```python


    # save fig
    output_path = os.path.join(output_directory, f"plot_page_{page_num+1}.pdf")
    plt.savefig(output_path, bbox_inches='tight')
    plt.close()

print(f"Finished plotting {total_records} records across {total_pages} pages.")
```