Independent Evaluation of Reroute Study

of Chevron's Rangely Pipeline to Salt Lake City Refineries

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Note: this report was originally prepared in August, 2012 based on initial alternative pipeline routing model runs. Several extensions to the original analysis were suggested and subsequent additional routing model runs were completed. The "Review Synopsis" section below has been amended to reflect the new information and an appended section, "Extended Alternative Route Analysis", at the end of the report has been added to describe and discuss the new routing model runs.

Review Synopsis

At the request of the mayor of Salt Lake City, a Reroute Study utilizing modern routing technology was completed for the termination portion of the existing Rangely Pipeline constructed in the 1950s. The study concluded that rerouting the current route is not desirable as the alternative routes studied pose significant problems. A follow-up independent evaluation of the study's approach, procedures, assumptions and conclusions was requested. This document reports the findings from an on-site visit to Houston to meet with the Chevron Pipeline routing team and considerable review of documents provided and follow-up discussions.

The Reroute Study uses proprietary GISPRO software that employs long established and extensively utilized Least Cost Path (LCP) methodology for routing. The system is designed to identify the most preferred pipeline routes based on specific mapped criteria, such as slope, proximity to roads, distance from environmentally sensitive areas or population centers, etc. The twenty one Criteria maps used in the study are normalized to a common "preference scale."

The individual *Criteria maps* are grouped into four different perspectives, or Themes (Consequences, Construction, Hazards and Environmental). The Criteria maps in each Theme are weight-averaged to reflect their relative importance in guiding pipeline routing. In turn, the aggregated *Theme maps* are weight-averaged for an *Overall Preference map*. The software then uses a well established route-finding algorithm to identify the path having the most accumulative preference (most preferred) from a beginning location to an ending location.

The GISPRO implementation of the Least Cost Path procedure is sound. The set of criteria maps, their calibration and weights used in the study were established in a special forum of pipeline routing, and GIS experts several years ago and are inline with those used throughout the industry. The iterative procedure using fixed weights for establishing the alternatives is adequate and follows company standards, but preferential weighting could add additional information about different routing perspectives.

Since the elongated routes A3 and A4 and their corridors share a common northern entry path toward the refinery and converge with route A2, these routes can dropped from serious further consideration. Generally speaking the Existing route mostly runs along the relatively flat terrain at the base of the foothills, while the A1 alternative mostly runs across the foothill toe-slope in the canyons leading to the city and the A2 route mostly runs cross-country in very rugged and forested terrain.

The study's general conclusion was that the routes cross extremely rough terrain with significant environmental and risk concerns, as well as being very challenging to construct and maintain. None of the alternative routes are desirable and do not provide a significant overall advantage to the Existing Rangely route. The specific enumerated conclusions in the study are valid.

A follow-on study was performed in light of the original study review's conclusions and recommendations. These extensions included executing four alternative scenarios reflecting different perspectives on pipeline routing for the final leg to the Salt Lake Pump Station. The preference surfaces used in routing were based on 1) **Construction** weighted considerations, 2) **Slope Only** consideration, 3) **Environmental** weighted considerations and 4) **People** weighted considerations. All four of the alternative routes started approximately three miles up East Emigration Canyon near the Freeze Creek confluence. In addition a fifth alternative was run that set the Salt Lake City limits as an "exclusion zone" that forced routing around the city. The results and discussion of these runs are included in an appendix at the end of this report

In this review, no inappropriate routing or analysis procedures were identified that would require changes in the analysis for both the original study and the follow-on study. The conclusions reached in both the original and follow-on studies are justified. While rerouting would shift the pipeline outside of the city limits, it would place it on sensitive and rugged terrain with limited access if a rupture occurred. Permitting would be difficult and time consuming with a very uncertain outcome. In the reviewer's experience none of the alternative routes identified are more suitable than the existing route and they pose considerable increased adverse impacts and risks.

The body and appendix of this review provides more detailed discussion and comment on the study's approach, procedures, assumptions and conclusions. A short list of comments identifying some technical aspects that might be useful for the GISPRO team is included.

Background

Chevron Pipe Line Company has assessed the feasibility of certain alternative pipeline routes from the Rangely, Colorado area to Salt Lake City refineries. The study used Chevron's proprietary software known as Geographical Information Systems Pipeline Route Optimization (GISPRO), a computer program designed to identify the most preferred pipeline routes using Geographic Information Systems technology based on specific mapped criteria. The Reroute Study identified four alternative routes and evaluated the alternatives with respect to the existing route (figure 1). The study concluded that rerouting the current Rangely Pipeline manually identified in the 1950s is not desirable.

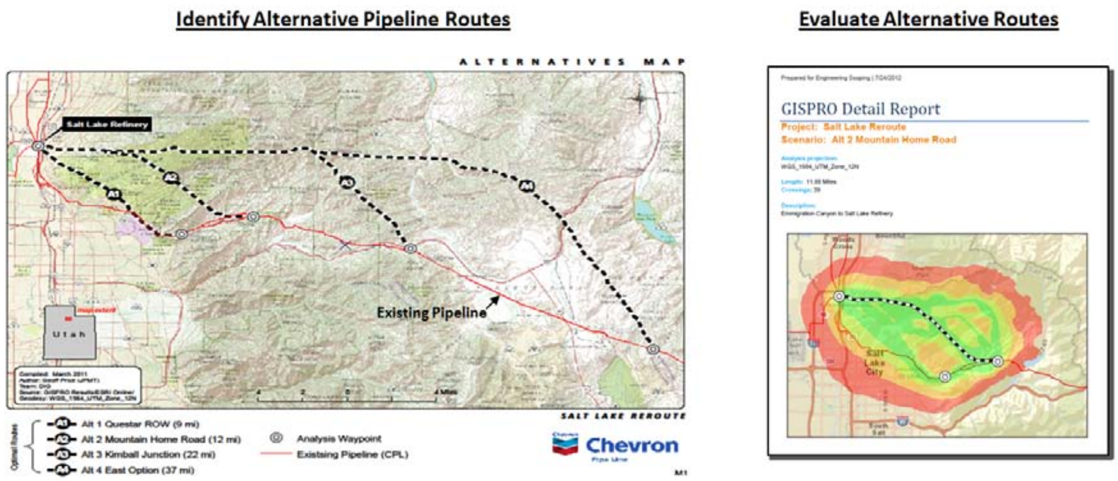


Figure 1. The Rerouting Study consisted of first identifying alternative pipeline routes and then evaluating the alternative routes.

At the request of Salt Lake City Mayor Ralph Becker, an independent evaluation of the Reroute Study was performed for the purpose of conferring to City officials the appropriateness of the Rangely Pipeline's current location. The confirming study was voluntarily undertaken by Chevron Pipe Line Company as a courtesy to the City and is not based on any regulatory requirement or jurisdictional basis.

Report Overview

The independent reviewer[1] made an on-site visit to Houston to meet with the Chevron Pipeline routing team. The day and half meeting provided an opportunity for detailed discussion and interactive presentation of the approach, assumptions, procedures, calibrations/weightings, results and conclusions of the Rerouting Study. Follow-up phone discussions and additional material requests supported the report preparation.

This independent review of the Reroute Study evaluates and critiques the methodology and procedures used. The findings are organized into seven sections:

- Approach— *discusses the Least Cost Path (LCP) methodology used in the GISPRO system to generate alternative routes.*
- Criteria— *identifies and comments on the map layers and sub-grouping classes used in the study.*
- Calibration— *describes the normalization of the Criteria map layers to a common scale of suitability from 1 (most preferred) to 9 (least preferred) ratings.*

- Weighting— *discusses the assignment of weights reflecting each map layer's relative importance used in weight-averaging the calibrated Criteria map layers into sub-groups (Themes) and, in turn, weight-averaging the Themes to derive a single Overall Preference map.*
- Alternate Scenarios— *comments on the procedures used to simulate numerous potential alternative routes and then to select the most promising ones for further comparison and evaluation.*
- Comparison/Evaluation— *comments on the procedures used for comparison and evaluation of the top re-routing alternatives.*
- Conclusion/Recommendations/Comments— *discusses the results of the Reroute Study and the interpretations/conclusions made in the report and lists suggested improvements in the Rerouting Study and general approach of GISPRO analysis for pipeline location.*

Approach

The GISPRO system used in this study is a software tool that helps determine the best route for a potential pipeline, based on weighted preferences regarding criteria for pipeline location and construction. For example, these preferences might take into consideration such spatial information as slope, proximity to roads, distance from environmentally sensitive areas or population centers, etc.

The software uses long established and extensively utilized Least Cost Path (LCP) methodology for routing. GPS routing in vehicles uses a similar approach to identify the best path between two locations along a discrete "vector" road network (series of interconnected line segments). However, when routing over continuous geographic space a "raster" grid is used (set of adjoining grid cells).

The relative "costs" of movement across each of the intervening cells between two locations is considered and the least accumulated cost (most preferred) path identifies the best route. It is important to note that "cost" in routing applications rarely refers to dollar cost. Rather the term "cost" refers generally to the relative impedance of movement, like varying speed limits on roads in GPS routing in determining the quickest route that forms the mainstay of E911 response within a city.

A backcountry emergency response system determines the relative ease of movement (on- and off-road "speeds") for each grid cell location depending on their travel conditions (steepness, vegetation density, rockiness, etc.). The continuous space LCP model starts at a dispatch center and simulates moving out in a pickup truck along the roads as far as possible, then off-loads an ATV and proceeds off-road as far as possible until conditions prohibit mechanized travel and then proceeds on foot. The result is an accumulated travel-time map and best/quickest route to all accessible locations throughout a project area measured in combined "truck + ATV + hiking" response time.

In GISPRO, the "costs" associated with pipeline routing are not measured in dollars or time, but in terms of relative preference or suitability for locating a pipeline at any location. The most preferred locations are those that have suitable conditions (e.g., gently sloped, low population density, near roads, minimal natural hazards, etc) expressed in a relative scale from lowest cost (most preferred) to highest cost (least preferred). The software then uses a well established route-finding algorithm to identify the path having the lowest accumulative "cost" from a beginning location to an ending location.

Figure 2 schematically shows the logical flow of the GISPRO analytical approach for locating the best pipeline routes throughout continuous geographic space. The approach progresses from Criteria map layers (base maps) to their weighted-averaging for relative importance for an overall Preference map, which in turn, guides the solution for the best route. In a strict technical sense, the procedure is not true optimization, but routinely identifies the "most preferred" route within a given set of assumptions (criteria, calibrations and weightings) and is widely used in numerous routing applications.

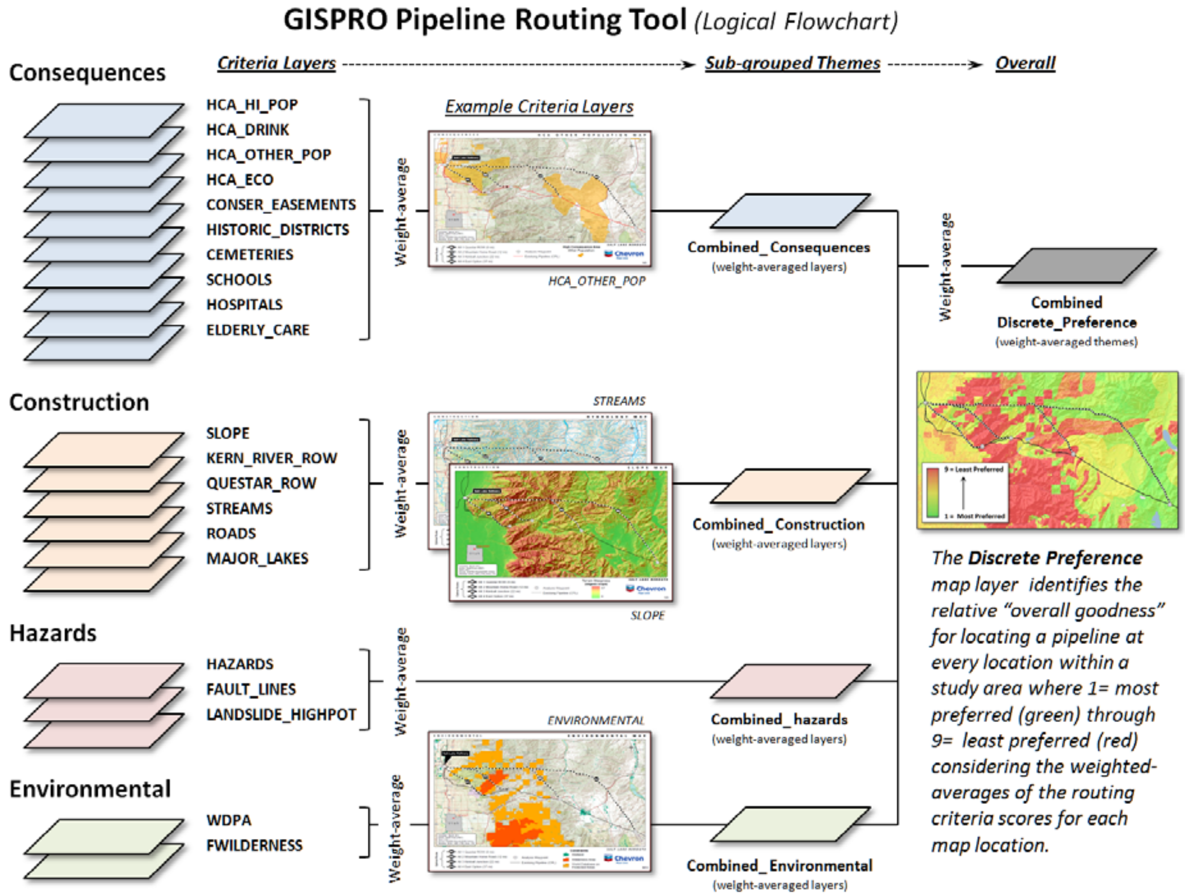


Figure 2. Logical flowchart of GISPRO processing to derive the Discrete Preference map layer that guides the routing algorithm.

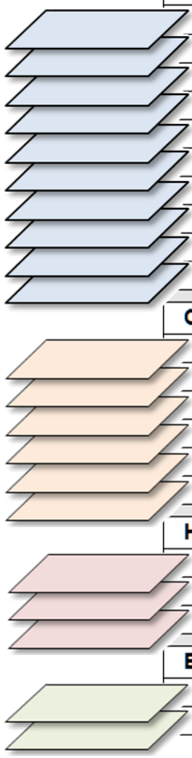
In generating the alternative routes for the reroute Study, several extended guidelines were considered—

- Dollar cost not to be considered as an evaluation decisive factor in the reroute evaluation.
- Route should avoid crossing Salt Lake City limits.
- Allow pipeline routing on National Forest lands.
- Remove existing pipeline ROW from consideration (program normally has a strong preference for existing ROWs).
- Limit the amount of criteria map layers to just the most significant ones (Utah has a very rich GIS database and too many layers dilute the process).

Criteria

Figure 3 lists the twenty one Criteria map layers (base maps) used in the Rerouting Study. Most of these maps are typically used in Chevron Pipeline routing projects with the addition of several special routing considerations in the Consequences theme (Conservation Easements, Historic Districts, Cemeteries, Schools, Hospitals and Elderly Care Facilities) and a couple in the Construction theme (existing Kern River and Questar right-of-ways).

Although Utah has a very rich GIS database, one must be frugile in choosing the set of Criteria layers to include, because too many layers tends to dilute the information needed to guide route-finding algorithm. The six special layers in the Consequences theme and the two in the Construction theme seem judicious.



Criteria Layers and Sub-grouping Themes	Relative Preference
Consequences (10 Criteria Layers considered)	
*High Consequence Area — **High Population***	*Prefer not to locate in a HCA*
*High Consequence Area — **Drinking Water***	*Prefer not to locate in a HCA*
*High Consequence Area — **Other Population***	*Prefer not to locate in a HCA*
*High Consequence Area — **Ecologically Sensitive***	*Prefer not to locate in a HCA*
Conservation Easements	*Prefer not to locate in an easement*
Historic Districts	*Prefer not to locate in a historic district*
Cemeteries	*Prefer not to locate in a cemetery*
Schools	*Prefer not to locate on school grounds*
Hospitals	*Prefer not to locate on hospital grounds*
ElderlyCareFacilities	*Prefer not to locate on care facility grounds*
Construction (6 Criteria Layers considered)	
Terrain Steepness (Slope)	*Prefer not to locate on steep terrain*
*Proximity to **Kern River Right-of-Way***	*Prefer to locate on or near ROW*
*Proximity to **Questar Right-of-Way***	*Prefer to locate on or near ROW*
Streams Crossings	*Prefer not to locate/cross streams*
*Proximity to **Roads***	*Prefer to locate near but not on roads*
MajorLakes	*Prefer not to locate in lakes*
Hazards (3 Criteria Layers considered)	
Hazards	*Prefer not to locate in high hazard areas*
FaultLines	*Prefer not to locate on known fault lines*
Landslide Potential	*Prefer not to locate in potential landslide areas*
Environmental (2 Criteria Layers considered)	
World Database on Protected Areas	*Prefer not to locate in WDPA areas*
Wilderness	*Prefer not to locate in wilderness areas*

Figure 3. Listing of the twenty one Criteria map layers (organized by themes) with statements describing their preferred conditions.

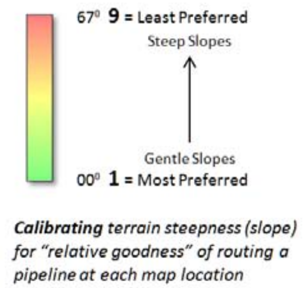
However, the introduction of the special Utah Criteria layers had minimal effect on the rerouting alternatives. The special Consequences layers had no effect on any of the four alternative routes generated as most of the features are sparsely distributed and primarily occur within the city. While the Questar ROW was utilized in Alternative 1, the Kern River ROW was not used in any of the alternative routes generated.

It is interesting to note that Chevron chooses not to use *Exclusion map* layers in their pipeline routing. Most LCP applications identify locations that cannot be crossed under any circumstances, such as absolutely avoiding active airport runways for locating electric transmission lines. They prefer to assign a high cost (9= least preferred) to such adverse conditions and then interpreting the routing results on an alternative-by-alternative basis whether to avoid certain areas. For example, they assigned a high cost to Major_Lakes (treated as a *relative barrier* that could be considered) instead of identifying them as areas to avoid (*absolute barrier* that completely restricts consideration).

Calibration

There are three levels of mapped criteria that are consideration: individual Criteria Layers (base maps), summaries by Theme Class and Overall Preference summary. The first step is to “calibrate” the various conditions for each of the individual *Criteria map layers* on a scale of 1 (most preferred) to 9 (least preferred) for pipeline routing.

For example, a map of terrain slope is calibrated as 1 (most preferred) = 0 to 5 degrees, 3 = 5 to 10, 4 = 10 to 20 degrees, 6 = 20 to 30, 8 =30 to 45 and 9 (least preferred) = 45 to 90, as shown in figure 4. Generally speaking, it is best that pipeline routing stay away from steep slopes (warmer red tones), socially delicate areas (e.g, visual exposure, etc), ecologically sensitive locations (e.g., sensitive habitats) and hazardous areas (e.g., rapid downhill flows), as well as construction considerations (e.g., difficult permitting, hydraulics and high construction and operating costs).



Slope (deg)	Preference
0 to 5 Degrees	1 Most preferred
5 to 10 Degrees	3
10 to 20 Degrees	4
20 to 30 Degrees	6
30 to 45 Degrees	8
45 to 90 Degrees	9 Least preferred

Figure 4. Calibration of each Criteria Map Layer”normalizes” all of the layers to common scale of “relative goodness” for pipeline routing expressed as 1= most preferred to 9= least preferred.

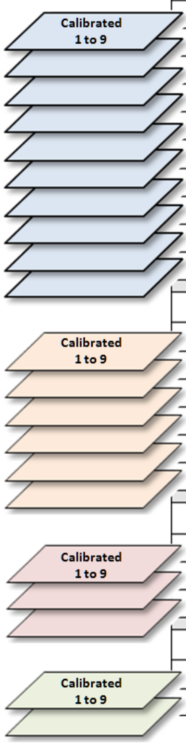
In a similar manner, all of the Criteria map layers for a GISPRO run are assigned values from 1 to 9 depending on the conditions present at each map location. For example, locations identified as a High Consequence Area due to high population densities (HCA_HI_POP map) are assigned a preference score of 9= leasted preferred and non-HCA locations are assigned a 1= most preferred. The result is that all of the criteria map layers are normalized to a common “goodness scale” for locating a pipeline based on the range of actual conditions.

It was noted that some of the Criteria layers were not calibrated to the full 1 to 9 extent of the normalization scale (HCA_Drinking, HCA_OtherPop, HCA_Eco, and Conservation Easements). It is general practice in LCP applications that all of the Criteria layers are calibrated to a common range or missleading “implicit double-weighting” of the layers occurs. However, with the exception of the HCA_drinking Water and HCA_otherPop map layers, the incorrectly calibrated maps do not occur within the alternative routing area and the impact of inconsistent normalization on alternative route solutions was minimal.

The *Calibration Step* is similar to a professer grading exams with each grid location in geographic space analogous to student seating in a large classroom. Each “student/cell” gets a grade from 1 (a most preferred; A grade) to 9 (a least preferred; F grade) depending on their “answers/conditions” on an exam/criteria layer. In the analogy, each calibrated Criteria map layer is analogous to a single exam. To calculate an overall semester grade, a professor weight-averages all of the exams and other graded materials depending on their relative importance.

Weighting

In the GISPRO system, the weighting step for generating an overall preference map involves two considerations— Theme and Overall weighting. The four enlarged-boldfaced type headings on the left side of figure 5 (Consequences, Construction, Hazards and Environmental) denotes grouping of the 21 criteria layers into similar classes of consideration. The *Theme Weighting Step* averages the calibrated Criteria layers within each theme giving more influence to some. In deriving the Hazards theme, for example, the Hazards theme is considered 6.49 times more important than the Landslide_HighPot layer in calculating the weighted average at each map location. The result of this processing is to group the Criteria maps into four new Theme maps reflecting their combined influence on routing.



Criteria Layers and Sub-grouping Themes	Influence Weights
Consequences	**3.33 …times important (most)**
Direct Conversion of ***HCA_HI_POP****_9*	*1.30 …most important (only slightly more)*
Direct Conversion of ***HCA_DRINK****_8*	*1.30 …most important (only slightly more)*
Direct Conversion of ***HCA_OTHR_POP****_5*	*1.30 …most important (only slightly more)*
Direct Conversion of ***HCA_ECO****_6*	*1.30 …most important (only slightly more)*
ConservationEasements	*1.00 …least important*
*Direct Conversion of SGID93_LOCATION_****HistoricDistricts***	*1.00 …least important*
*Direct Conversion of SGID93_LOCATION_****Cemeteries***	*1.00 …least important*
*Direct Conversion of SGID93_LOCATION_****Schools***	*1.00 …least important*
*Direct Conversion of SGID93_LOCATION_****Hospitals***	*1.00 …least important*
*Direct Conversion of SGID93_LOCATION_****ElderlyCareFacilities***	*1.00 …least important*
Construction	**1.00 …times important (least)**
Slope *of USGS_NED_1_3_ARCSECOND3*	*7.32 …most important*
Euclidean Distance of layer ***Kern_River_ROW****_lines*	*5.92*
Euclidean Distance of layer ***Questar_ROW****_lines*	*5.92*
*Direct Conversion of SGID93_WATER_****Streams***	*3.52*
Euclidean Distance of layer ***Road****_Utah_CFCC*	*2.86 …least important (usually 1.00)*
*Direct Conversion of SGID93_WATER_****UtahMajorLakes***	*0.00 …not considered*
Hazards	**1.81 …times important**
Direct Conversion of ***Hazards***	*6.49 …most important*
Direct Conversion of ***FaultLines***	*3.80*
Direct Conversion of ***Landslide_HighPot***	*1.00 …least important*
Environmental	**2.99 …times important**
Direct Conversion of ***WDPA****_Clip*	*1.00 …equally important*
Direct Conversion of ***Wilderness*** *clip*	*1.00 …equally important*

Figure 5. Listing of the influences weights for deriving the Theme map layers and combining them into a single Overall Preference map layer used to guide the identification of the most preferred route.

The *Overall Weighting Step* uses the same weight-averaging procedure to combine the four theme maps. For example, the Environmental theme is considered the most important consideration in routing a pipeline with an importance/influence weight that is 2.99 times more important than Construction considerations.

The basic set of criteria maps and their calibrations and weights used in the Routing Study were established in a special forum of pipeline routing and GIS experts several years ago and are inline with those used throughout the industry. These parmeters are generally used in Chevron pipeline routing projects. It is interesting to note that Construction considerations are weighted the least important and Consequences the most in deriving the Overall Preference map layer guiding the routing.

Alternate Scenarios

Alternate routes were simulated by identifying different starting locations along the Existing pipeline route (figure 6). Using the corporate standard calibration and weighting settings, potential starting locations were successively moved back from the refinery until the rerouting first circumvented the city limits (A1 start). Similar iterations were run to identify starting points of three additional distinctly different reroutes (A2, A3 and A4).

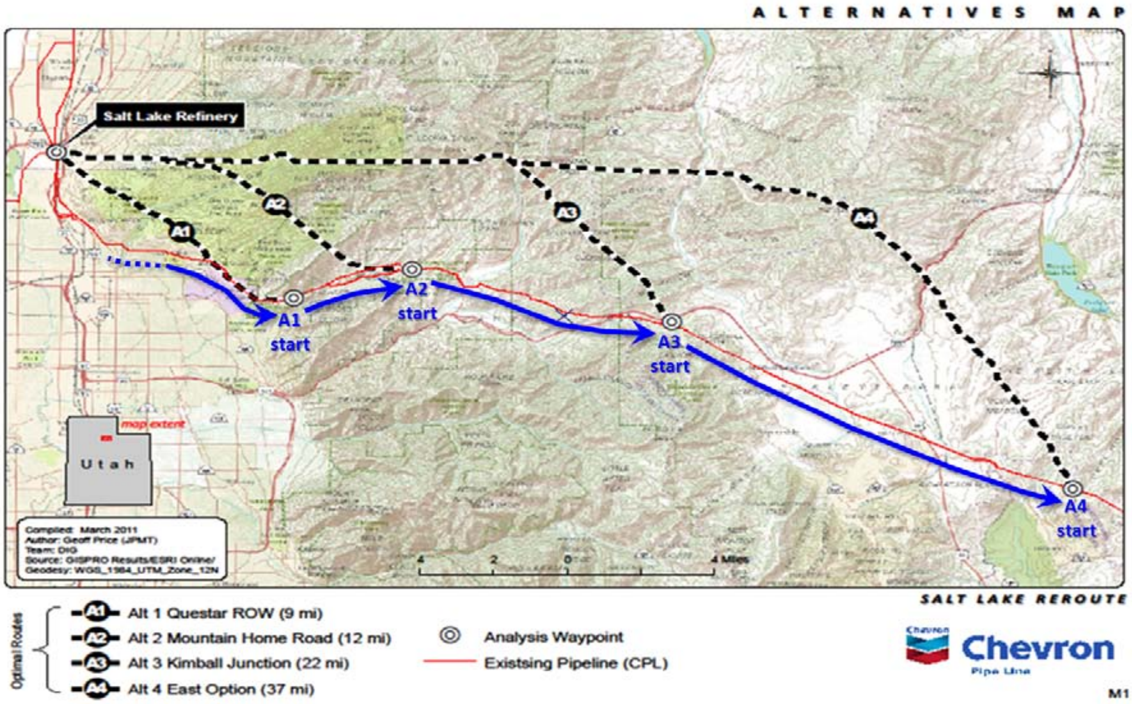


Figure 6. Alternate routes were identified by successiveley moving potential starting locations back along the existing pipeline route until four distinctly different alternatives were identified.

Figure 7 shows the best corridors for rerouting with green tones indicating the most suitable locations for adjustments in the computer generated "most preferred" paths (top 1% of all possible routes). The warmer reddish tones identify locations with significant undesirable conditions that make them effectively unsuitable for routing.

Note that most of the Existing Route (red line) coincides with the top one percent of the best routes (green zone). However, most of the portion of the Existing Route between the A3 and A4 starting locations occurs within the top eight percent best alternative routes (red zone). It is likely that the manual routing done in the 1950s considered the federal ownership of lands to the north and relatively rugged terrain as being less suitable than continuing the westerly routing.

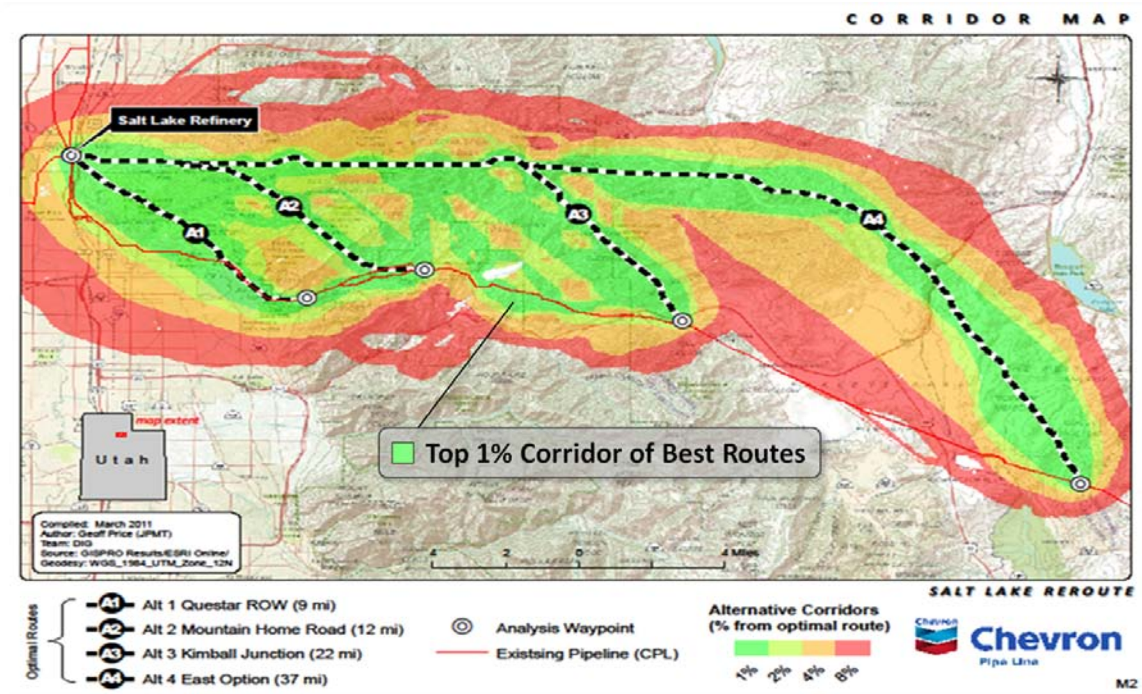


Figure 7. Corridors representing the set of top potential routes (green) provide information for deviating an alternative route if necessary.

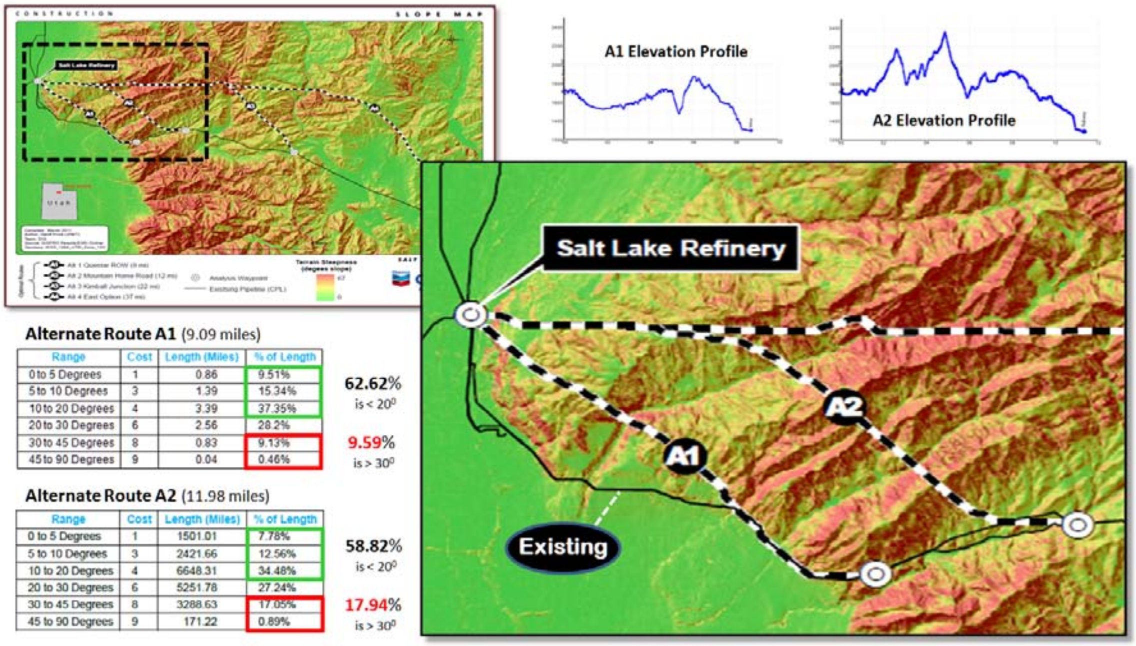
The Rerouting Study's approach of successively repositioning possible starting points generated an appropriate and valid set of alternative routes under a constant set of weighting considerations. Additional movements of starting locations along the Existing Route were not considered as additional rerouting alternatives would likely exceed forty miles of new pipeline alignment requiring extensive permitting and traversing of rugged terrain.

An alternative approach for identifying alternative routes used in many LCP applications would be to assign the city as an Exclusion area (absolute barrier) and consider the entire Existing pipeline as a starting feature which lets the algorithm identify the most appropriate starting. Technically speaking, this approach places the entire Existing route on the accumulation cost surface derived from the refinery (destination point) and automatically identifies the lowest point (least accumulated cost) as the starting point.

Also, many LCP applications extend the point-to-point routing information by simulating different routing perspectives (changing weights). In these scenarios the overall weights are systematically adjusted to make one of the Theme layers more important than the others, such as Consequences being five times more important than Construction, Hazards and Environmental considerations. In turn, each Theme's is forced to be more influential than the others which results in four possible routes expressing different perspectives. In this approach, comparison of the results identifies locations "preferred" by each of the routing perspectives (e.g., where Environmental considerations want to place the route).

Comparison/Evaluation

Since the elongated routes A3 and A4 and their corridors share a common northern entry path to the refinery and converge with route A2, these routes can dropped from serious further consideration. Detailed reports for the A1 and A2 alternatives were generated to summarize the coincidence of the alternative and each of the Criteria map layers. For example, the tables in the lower-left portion of figure 8 summarize slope conditions along the routes and the elevation profile graphs in the upper-right portion show the changes in topography.



Alternate Route A1 (9.09 miles)

Range	Cost	Length (Miles)	% of Length
0 to 5 Degrees	1	0.86	9.51%
5 to 10 Degrees	3	1.39	15.34%
10 to 20 Degrees	4	3.39	37.35%
20 to 30 Degrees	6	2.56	28.2%
30 to 45 Degrees	8	0.83	9.13%
45 to 90 Degrees	9	0.04	0.46%

62.62% is < 20⁰

9.59% is > 30⁰

Alternate Route A2 (11.98 miles)

Range	Cost	Length (Miles)	% of Length
0 to 5 Degrees	1	1501.01	7.78%
5 to 10 Degrees	3	2421.66	12.56%
10 to 20 Degrees	4	6648.31	34.48%
20 to 30 Degrees	6	5251.78	27.24%
30 to 45 Degrees	8	3288.63	17.05%
45 to 90 Degrees	9	171.22	0.89%

58.82% is < 20⁰

17.94% is > 30⁰

Figure 8. Summary of the terrain conditions along alternative routes A1 and A2.

Note that both alternative routes have similar proportions of gentle to moderate slopes (about two-thirds), but A2 has significantly more steep terrain (18% versus 10%). The commonly scaled profiles show where the dramatic changes in elevation occur along the routes.

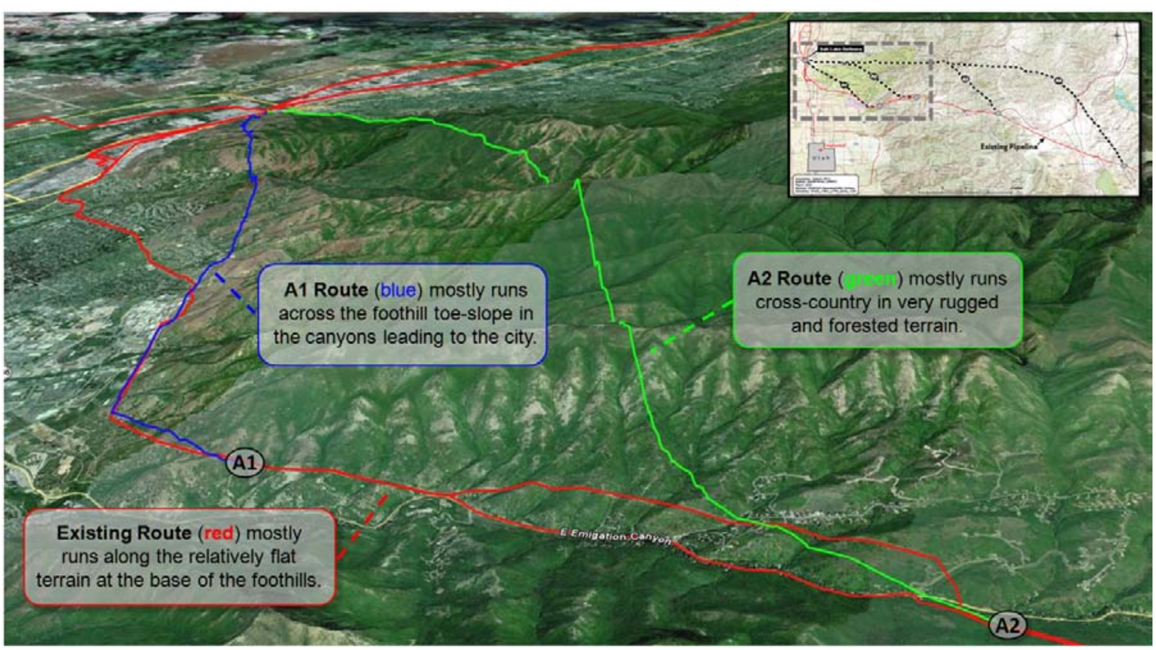


Figure 9. Google Earth display showing a 3D perspective of the terrain with aerial image backdrop and routes superimposed.

In addition to the coincidence summaries for each of the Criteria map layers, the reports summarize construction considerations that are used in spreadsheets for evaluating construction costs and feasibility. For example, both A1 and A2 alternative routes have similar rock classification characteristics; slightly more water and road crossings for A2; and significantly more industrial/suburban/urban routing for A1. While these summaries are critical from an engineering perspective they are less useful for evaluation of alternative routes outside of the corporation.

Interactive visualization of the alternative routes with aerial image backdrop provides for contextual interpretation of the actual conditions along the routes. Figure 9 is a screen grab of a Google Earth scene with the Existing, A1 and A2 routes superimposed onto a 3D perspective of the landscape. Note that the Existing route (red) mostly runs along the relatively flat terrain at the base of the foothills; the A1 route (blue) mostly runs across the foothill toe-slope in the canyons leading to the city; and the A2 route (green) mostly runs cross-country in very rugged and forested terrain.

Conclusions

The Reroute Study team reviewed and discussed the comparison and evaluation results for all of the alternative routes developed. Their general conclusion was that the routes cut across extremely rough terrain with significant environmental and risk concerns, as well as being very expensive to construct and maintain. None of the alternative routes are desirable and do not provide a significant overall advantage to the Existing Rangely route. Specific conclusions and comments of the Reroute Study are—

Right of Way and Permit Requirements:

- Environmental Impact Statement through Wasatch National Forest. Minimum of one year for first draft of study and another year for public comments and associated revisions
- USFS / BLM / Army Corps / State of Utah Environmental related permits (note: minimum of one additional year after the Environmental Impact Statement approval)
- Private condemnation for R.O.W. will be challenging

Alternative Route Conclusions:

- All the routes cross though the Wasatch National Forest
- All routes lay near or through wilderness and protected areas
- Routes are in very rugged terrain, difficult to safely construct
- Routes are very remote so access for maintenance activities will be very difficult and possibly disturb wildlife
- Cannot avoid watersheds that flow into Salt Lake City
- Cannot avoid populated areas – Park City and SLC bedroom communities
- Model prefers the existing pipeline route

Recommendations

In this review, no inappropriate routing or analysis procedures were identified that would require changes in the analysis. The study's conclusions are justified. While rerouting would shift the pipeline outside of the city limits it would place it on sensitive and rugged terrain with limited access if a rupture occurred. Permitting would be difficult and time consuming with a very uncertain outcome. In the reviewer's experience none of the alternative routes identified in either the original or the follow-on effort are more suitable than the existing route and pose considerable increased adverse impacts, cost and risks.

Comments and Technical Suggestions

Although no required changes or extensions to the study are recommended, the following technical comments and considerations might be useful for the GISPRO team for future routing applications—

1) Rigorously assess the set of criteria map layers for only significant/important layers to avoid dilution of influence or missed layers.

2) Insure that each criteria map layer has 1 to 9 calibration range to insure normalization consistency (HCA_Drinking, HCA_OtherPop, HCA_Eco, and Conservation Easements).

3) In establishing weights for weight-averaging the least important map layer is assigned 1 and all of the other maps in the group are assigned weights that are integer or fractional multiples of the base weight. For example, terrain slope is considered 2.56 times more important than proximity to roads (rescaled to base 1 for least important by considering current weights of 5.92/2.86).

4) Develop alternative routing scenarios from a single location outside SLC limits generating four alternatives that preferentially weight Social/Cultural considerations (alternative A), Environmental considerations (alternative B), Engineering considerations (alternative C) and equally weighted considerations (alternative D).

5) Generate graphic and tabular comparisons of alternative routes and existing in-place Rangely Pipeline route for the SLC area of interest; "*fly-by*" of 1-9 ratings for discrete cost sub-groupings to show spatial pattern of most and least preferred sections along each route; create an *overall ranking map* of the most preferred locations by calculating the sum of binary maps of the top two percent corridors (total= 0 corridor routes prefer through total= 5 (all) corridors prefer); develop a *spreadsheet summary* area/proportion of each route by the discrete cost ratings for each sub-grouping.

6) In developing these scenarios the Chevron team identified the set of Themes and Criteria Map Layers they believed were the most important determinants driving each scenario. In each instance, a new model construction was generated without direct relationship to each other or the standard Chevron routing model used in the earlier runs. While the "re-constructed" model approach is valid and often used, it does not provide continuity for directly assessing the relative impact among the four scenarios. An alternative scenario generation technique used in LCP routing is to retain a consistent model structure (e.g., the Chevron Standard model) while varying the Theme weights to simulate increased influence by each Theme perspective. For example, setting the Construction Theme weight to 10.0 and the other themes to 1.0 simulates a construction dominated perspective as one of the scenarios (figure A4). In future applications, Chevron might consider the "sequencing of preferential weighting" method in developing consistent alternative scenarios.

7) It is important to note that the use of "exclusion areas" that prohibit routing is a powerful option in LCP routing. Simply assigning a high "cost" to these areas only discourages routing and the effect is diluted by weight-averaging with other layers. The GISPRO team might consider more extensive use of "exclusion areas" when attempting to force a route around unsuitable areas, such as the SLC limits in this application.

8) To aid comparison/evaluation of alternative routes, it is useful to utilize a coincidence summary for the Overall preference map as well as the individual criteria map layers. Also, use of an embedded graphic showing the actual preference values (1 to 9) is useful in visualizing the spatial distribution of routing preference along the route. An effective display could be a stacked series of thick offset routes for each of the four Theme map layers plus the Existing route colored from green (most preferred) to red (least preferred). This enables members of the design team to quickly see where agreement and differences occur between the perspectives.

Materials Used:

GISPRO User Guide (Version 1.1.1), New Century Software, Fort Collins, Colorado, November 2011.

GISPRO Detailed Reports for Alternative 1 (Questar ROW) and Alternative 2 (Mountain Home Road), reports generated on-site.

Salt Lake Crude Pipeline Re-route Study, PowerPoint presentation by Chevron Pipeline, April 9, 2012.

General References:

Pipeline Route Selection: *A Jumpstart for International Growth*, feature article by Geoff Price for GeoWorld, May 2011.

Routing and Optimal Paths, an online book chapter in Beyond Mapping III, Topic 19 by J.K. Berry. Posted online at www.innovativegis.com/basis/MapAnalysis/Topic19/Topic19.htm.

A Web-based Application for Identifying and Evaluating Alternative Pipeline Routes and Corridors, paper by J.K. Berry, M.D. King and C. Lopez for GITA Oil and Gas Conference, Houston, Texas, September 20-23, 2004. Posted online at www.innovativegis.com/basis/present/GITA_Oil&Gas_04

Optimal Path Analysis and Corridor Routing: *Infusing Stakeholder Perspective in Calibration and Weighting of Model Criteria*, paper by J.K. Berry for GeoTech Conference, Toronto, Ontario, Canada, March 28-31, 2004. Posted online at www.innovativegis.com/basis/present/GeoTec04/GIS04_Routing.htm

E911 for the Backcountry*,* online book Beyond Mapping III, by J.K. Berry, Topic 29, Spatial Modeling in Natural Resources. Posted online at www.innovativegis.com/basis/MapAnalysis/Topic29/Topic29.htm#Emergency_response

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[1]***Joseph K. Berry*** *is a leading consultant and educator in the application of Geographic Information Systems (GIS) technology. He is the principal of Berry and Associates // Spatial Information Systems (BASIS), consultants and software developers in GIS technology and the author of the "Beyond Mapping" column for GeoWorld magazine since 1989. He has written over two hundred papers on the theory and application of map analysis techniques, and is the author of the popular books Beyond Mapping (Wiley, 1993), Spatial Reasoning (Wiley 1995) and Map Analysis (GeoTec Media, 2007). Since 1976, he has presented college courses and professional workshops on geospatial technology to thousands of individuals from a wide variety of disciplines. Dr. Berry conducted basic research and taught courses in GIS for twelve years at Yale University's Graduate School of Forestry and Environmental Studies, and is currently the W. M. Keck Visiting Scholar in Geosciences at the University of Denver and an Adjunct Faculty member in Natural Resources at Colorado State University.*

Dr. Berry's experience in Least Cost Path routing is extensive. Since the early 1980s he has developed and enhanced algorithms for implementing LCP and applied the procedures for such diverse projects as forest haul road planning, pipe and electric transmission line routing, off-road emergency response, overland flow and spill modeling, risk avoidance for combat helicopter routing and optimal path analysis for in-store shopper movement.

Extended Alternative Route Analysis

(Appended November 7, 2012)

Approach

The procedural comments 1-3 in the original August review were extensively discussed and directly addressed in future routing model runs:

1) Rigorously assess the set of criteria map layers for only significant/important layers to avoid dilution of influence or missed layers.

2) Insure that each criteria map layer has 1 to 9 calibration range to insure normalization consistency (HCA_Drinking, HCA_OtherPop, HCA_Eco, and Conservation Easements).

3) In establishing weights for weight-averaging the least important map layer is assigned 1 and all of the other maps in the group are assigned weights that are integer or fractional multiples of the base weight. For example, terrain slope is considered 2.56 times more important than proximity to roads (rescaled to base 1 for least important by considering current weights of 5.92/2.86).

Structural comments 4-5 were extensively discussed and additional routing model runs incorporating alternative scenarios were completed:

4) Develop alternative routing scenarios from a single location outside SLC limits generating four alternatives that preferentially weight Social/Cultural considerations (alternative A), Environmental considerations (alternative B), Engineering considerations (alternative C) and equally weighted considerations (alternative D).

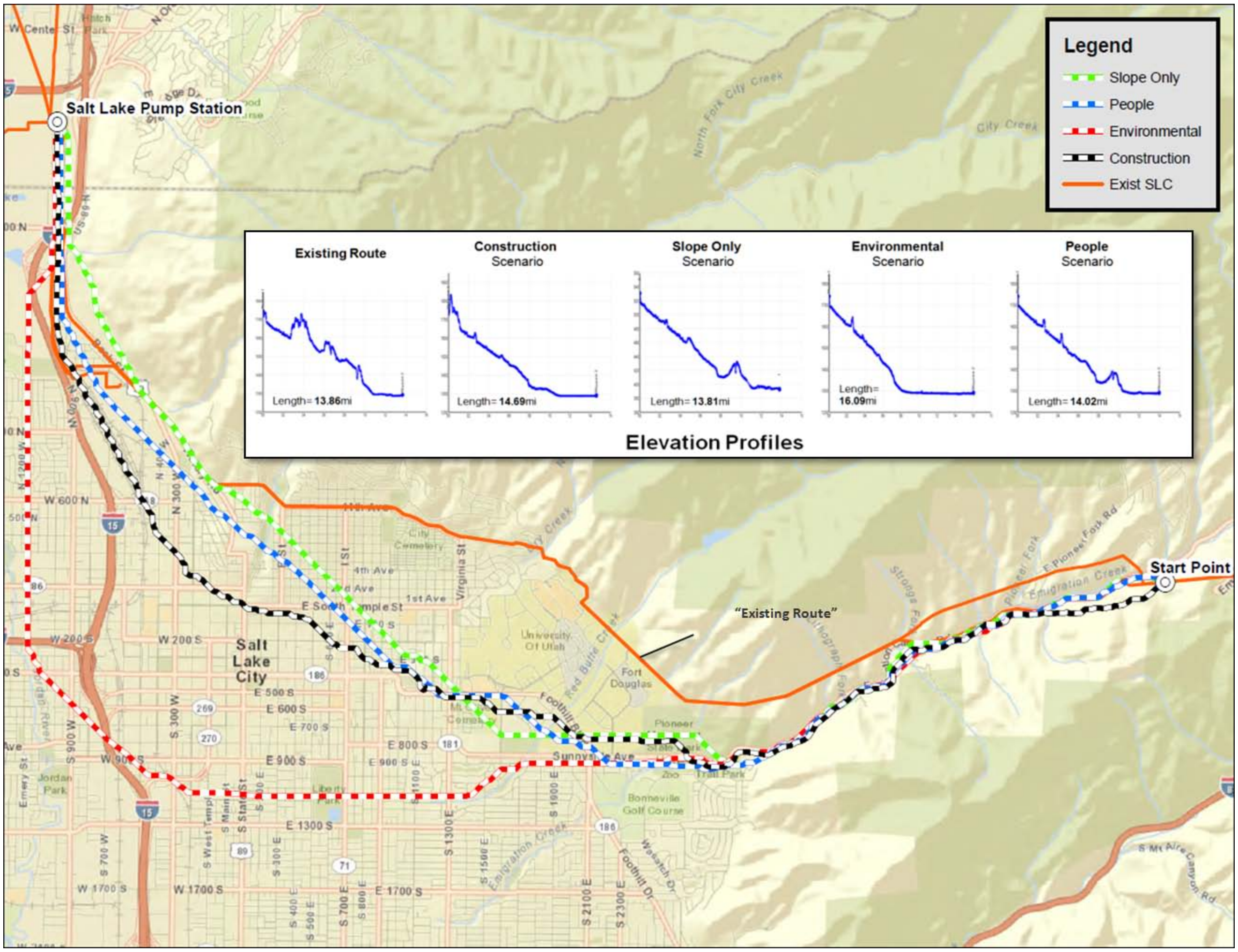
5) Generate graphic and tabular comparisons of alternative routes and existing in-place Rangely Pipeline route for the SLC area of interest; "*fly-by*" of 1-9 ratings for discrete cost sub-groupings to show spatial pattern of most and least preferred sections along each route; create an *overall ranking map* of the most preferred locations by calculating the sum of binary maps of the top two percent corridors (total= 0 corridor routes prefer through total= 5 (all) corridors prefer); develop a *spreadsheet summary* area/proportion of each route by the discrete cost ratings for each sub-grouping.

Four alternative scenarios were run to reflect different perspectives on pipeline routing for the final leg to the Salt Lake Pump Station. The preference surfaces used in routing were based on 1) **Construction** weighted considerations, 2) **Slope Only** consideration, 3) **Environmental** weighted considerations and 4) **People** weighted considerations (specific weighting criteria are identified and discussed in the next section). All four of the alternative routes started approximately three miles up East Emigration Canyon near the Freeze Creek confluence. This location corresponds to the A2 starting location derived in the initial set of alternatives that had provided two alternative routes around the city under the standard GISPRO runs.

Results

All four of the additional alternative routes reflecting different perspectives followed the canyon toward the southwest then veered northwest along the foothills (figure A1). The **Slope Only** alternative held closest to the foothill's toe slope. The **People** weighted scenario closely aligned with the *Slope Only* alternative as it favored avoiding areas of high housing density within the city. The **Construction** weighted scenario shifted further into the city by its favorable consideration of being near existing infrastructure corridors. The **Environmental** weighted scenario extends further into the city by its consideration of limiting crossing open and flowing water and lack of consideration for avoiding high population density.

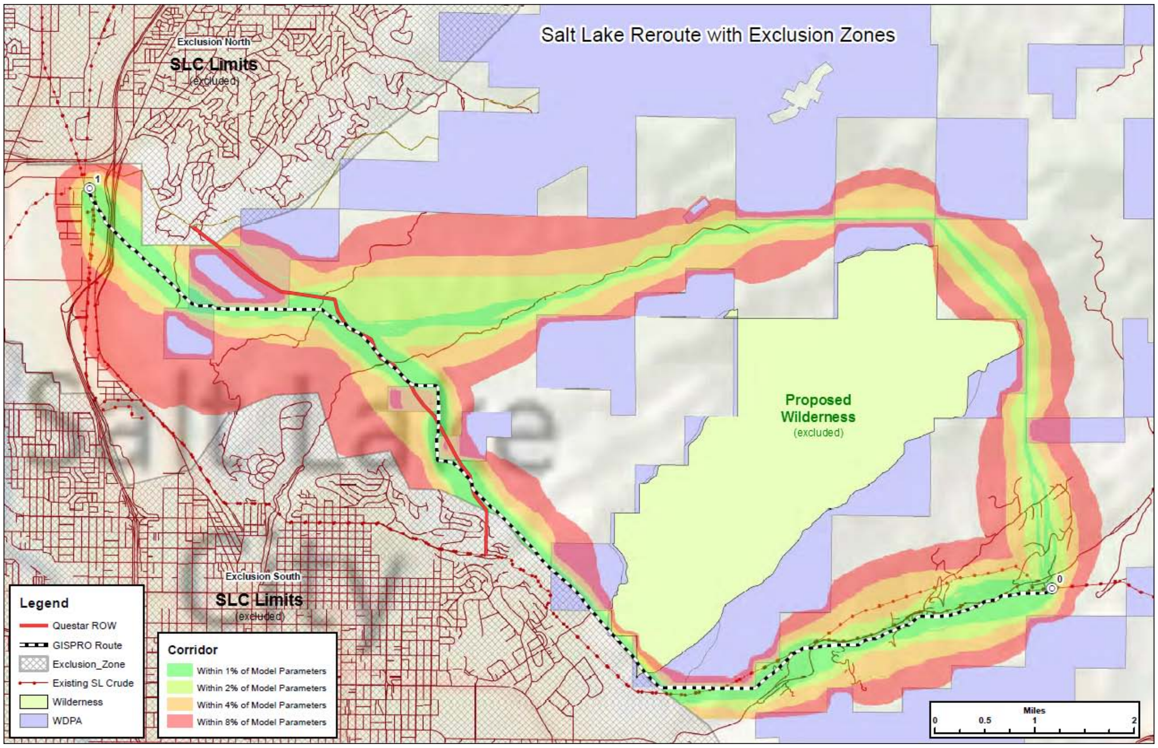
It is interesting to note that all four alternative routing scenarios extend further west into the city than the existing pipeline route. This is primarily due to the influence of 1) avoiding steeper slopes contained to at least a minimal degree in all of the alternatives that avoids an overland route through the mountains and 2) the relatively less dense housing density near the foothills rise.



<u>Figure A1</u>. Alternative pipeline routes considering different preference weightings for Construction, Slope, Environmental and People considerations.

In light of these results, a fifth alternative was developed that incorporated "exclusion" zones that prohibit routing (figure A2). Two exclusion zones were combined considered to form a **SLC City Limits** absolute barrier that forces the potential pipeline route outside of the city. The model run considered both Construction and Environmental considerations with Environmental concerns weighted nearly three times more important.

Note that the routing corridor splits around the proposed wilderness area with the optimal route aligned to the south and runs along the toe slope of the foothills, just outside of the city limits. The green portion of the corridor identifies potential routes that are within 1% of the optimal route suggesting that the northern routing possibilities are nearly as good as the southern. However, the remoteness, environmental sensitivity and permitting difficulties of locating in mountainous terrain, as well as increased construction costs, tends to favor the southern route.



<u>Figure A2</u>. Alternative Route and Corridor considering exclusion zones of Salt Lake City limits and proposed wilderness area.

Technical Considerations and Discussion

Table A1 identifies the routing model logic (Themes/Layers considered in the model and their relative Weights) for the four alternative perspective scenarios generated. It is important to note that none of the four scenarios took an overland path through the mountains and that they all followed the canyon toward the southwest, then veered northwest paralleling the foothills. This primarily was due to the prominent role of the Slope criteria layer that played in all four of the scenarios.

Table A1. Routing Model Logic for Alternative Senarios		
Construction Weighted Scenario **Results:** Length= **14.69** miles; Crossings= **0**		
Theme/Layer	**Influence**	**Comments**
Construction	<**1**>	Only Theme considered
Terrain Slope	7.32	Over seven times more important (**most important** Criteria Layer in the Construction Theme)
Road Proximity	2.86	Nearly three times more important
Railroad Proximity	1.00	Base Criteria Layer reference (**least important**)
Slope Only Scenario **Results:** Length= **13.81** miles; Crossings= **122**		
Theme/Layer	**Influence**	**Comments**
Slope	<**1**>	Only Theme considered
Terrain Slope	<1.00>	Only criteria layer considered
Environmental Weighted Scenario		

Results: Length= **16.09** miles; Crossings= **0**

Theme/Layer	Influence	Comments
Environmental	**2.99**	Nearly three times more important (**most important** Theme)
WD Protected Areas	16.67	All Criteria Layers equally weighted
Wilderness	16.67	All Criteria Layers equally weighted
Water/Streams	16.67	All Criteria Layers equally weighted
Lakes	16.67	All Criteria Layers equally weighted
HCA_Drinking	16.67	All Criteria Layers equally weighted
HCA_Eco	16.67	All Criteria Layers equally weighted
Construction	**1.00**	Base Theme reference (**least important** Theme)
Terrain Slope	<1.00>	Only criteria layer considered

People Weighted Scenario

Results: Length= **14.02** miles; Crossings= **0**

Theme/Layer	Influence	Comments
People	**3.33**	Over three times more important (**most important** Theme)
HCA_High_Pop	1.33	All Criteria Layers equally weighted
HCA_Other_pop	1.33	All Criteria Layers equally weighted
Construction	**1.00**	Base Theme reference (**least important** Theme)
Terrain Slope	<1.00>	Only criteria layer considered

All but the Environmental scenario resulted in similar routings that passed through the eastern edge of the city. The Environmental route took a much longer path that swings much farther to the west passing though much of the city. Note that the existing pipeline route is the farthest east and having the least impact on population centers.

A curious result is the 122 crossing recorded for the Slope Only scenario, while the other three scenarios had none.

In developing these scenarios the Chevron team identified the set of Themes and Criteria Map Layers they believed were the most important determinants driving each scenario. In each instance, a new model construction was generated without direct relationship to each other or the standard Chevron routing model used in the earlier runs.

While the "re-constructed" model approach is valid and often used, it does not provide continuity for directly assessing the relative impact among the four scenarios. An alternative scenario generation technique used in LCP routing is to retain a consistent model structure (e.g., the Chevron Standard model) while varying the Theme weights to simulate increased influence by each Theme perspective. For example, setting the Construction Theme weight to 10.0 and the other themes to 1.0 simulates a construction dominated perspective as one of the scenarios (figure A4). In future applications, Chevron might consider the "sequencing of preferential weighting" method in developing consistent alternative scenarios.

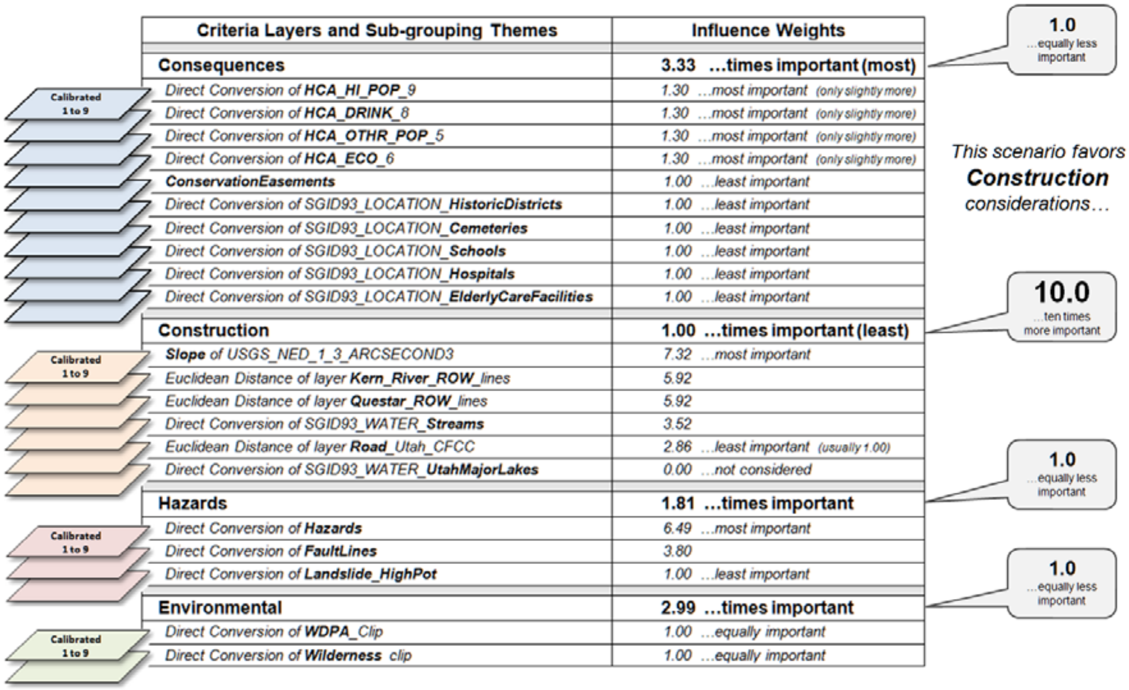


Figure A4. Consistent Alternative Emphasis Scenarios are generated by successively adjusting the standard model (benchmark) to favor one of the Themes over the others (the Construction Theme perspective favored in this example).

The final "City Exclusion" alternative considered both Construction and Environmental factors, with the Environmental concerns weighted nearly three times more important (Table A2). The corridor of optimality extends overland in the mountainous terrain and splits around the Proposed Wilderness Area. The optimal route is pushed considerably east of the existing pipeline route along the top of the foothills.

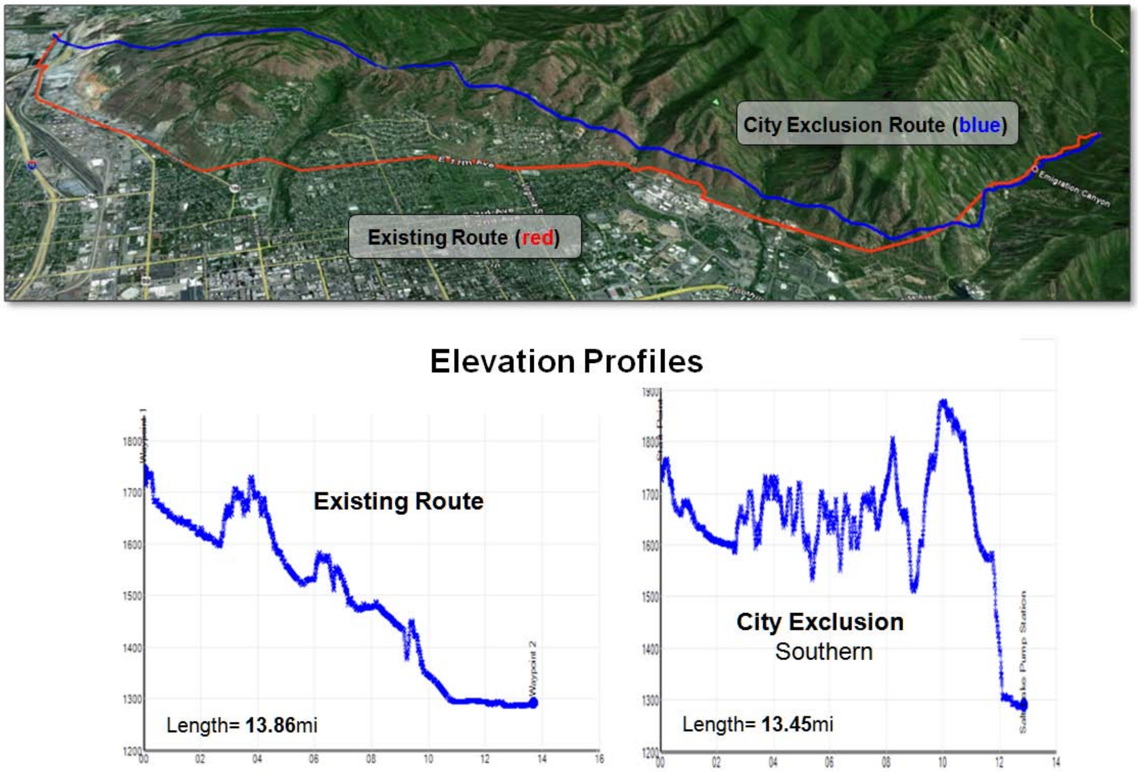
Table A2. Routing Model Logic for City Exclusion Senario

Exclusion Scenario

Results: Length= **13.45** miles; Crossings= **0**

Theme/Layer	Influence	Comments
Environmental	**2.99**	Nearly three times more important (**most important** Theme)
WD Protected Areas	1.00	Both Criteria Layers equally weighted
Wilderness	1.00	Both Criteria Layers equally weighted
Construction	**1.00**	Base Theme reference (**least important** Theme)
Terrain Slope	7.32	About two and half times more important (**most important** Criteria Layer in the Construction Theme; 7.32/2.86= 2.56)
Questar ROW Proximity	5.92	About two times more important (5.92/2.86= 2.07)
Road Proximity	2.86	Base Criteria Layer reference (**least important**)
Exclusions	**--**	Treated as an absolute barrier to pipeline routing
City Exclusion (north)	--	Treated as an absolute barrier to pipeline routing
City Exclusion (south)	--	Treated as an absolute barrier to pipeline routing

This alternative route in the mountainous terrain has several drawbacks—1) difficult and impactful construction, 2) slicing through the steep uplands of several watersheds, 3) high visual exposure to the city and recreation areas, and 4) extremely rugged elevation profile requiring additional pumping (figure A5).



<u>Figure A5</u>. The City Exclusion scenario has a significantly more rugged elevation profile.

It is important to note that the use of "exclusion areas" that prohibit routing is a powerful option in LCP routing. Simply assigning a high "cost" to these areas only discourages routing and the effect is diluted by weight-averaging with other layers. The GISPRO team might consider more extensive use of "exclusion areas" when attempting to route around unsuitable areas, such as the SLC limits in this application.