A GIS Based Pipeline Route Selection Process

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INTRODUCTION

Metropolitan Water District of Salt Lake & Sandy (MWDSLS) recently began the design process for the Point of the Mountain Aqueduct (POMA). This 60-inch diameter pipeline must convey finished water from the proposed Point of the Mountain Water Treatment Plant (POMWTP) approximately 12 miles to the Little Cottonwood Treatment Plant (LCWTP) and to a number of delivery points in between. The selection of the pipeline route was a key part of the overall project conceptual design.

The POMA alignment will be constructed through highly developed areas of two major cities. The majority of this area consists of residential and commercial development, with very little available open space remaining for new pipeline right-of-way (ROW). The aqueduct will cross railroads, canals, creeks, and parks that are located between the two plants. It will be located within existing narrow rights-of-way including canals and residential streets. In addition, the pipeline may encounter sensitive seismic areas that include liquefaction zones along the valley floor and the Wasatch Fault zone near the foot of the mountains. An alignment for the POMA was established that would minimize impacts to neighboring communities, and that would be cost effective to construct in terms of length and difficulty of construction within the established ROW.

PIPELINE ROUTE SELECTION PROCESS

The idea of developing a process to select an optimum pipeline alignment between two points is not new. A number of previous route selection studies have been conducted for large transmission pipelines similar to the POMA[i,ii]. While there are some differences between the ways the studies are conducted, the same basic issues are always addressed. These issues include cost, availability of land, and public concerns and desires in the communities through which the pipelines are aligned.

Route Selection Process Summary

It is understood that the construction of a large diameter transmission pipeline through heavily developed cities will create many challenges. There will be many engineering obstacles, environmental issues, construction issues, and general public concerns related to the construction of a pipeline of this size and length. The fundamental objective of this route selection process was to provide a rational basis that could be used to narrow down hundreds of potential alternatives to one final alignment corridor. The route selection process must be justifiable to all stakeholders that may be impacted by the new pipeline, both during construction and into the future of its operation. The logical process by which the alignment was selected was based on construction costs as well as important non-cost issues.

A route selection process was established for the POMA based upon the following fundamental concepts:

1. A study area must be defined to encompass the entire region through which the pipeline may be located. No area should be eliminated based upon preconceived ideas.
2. All possible alignments for the pipeline must be considered before eliminating alternatives.
3. A justifiable method must be used to provide a basis for eliminating alternatives from further consideration. This method must establish a logical process for moving from a large number of potential alternatives to the final recommended corridor.

The route selection process was organized into three levels of analysis, starting with all possible alternatives and narrowing them down to a final pipeline corridor. The three levels of analysis with their associated descriptions are summarized in Table 1.

Table 1
Pipeline Route Selection Process

Level	Description	Remarks
1	Pipeline Segment Analysis	Included the definition of a study area to contain all possible pipeline routes from POMWTP to LCWTP. All streets and corridors in the study area were considered as possible alternatives. Each segment was evaluated based upon its estimated degree of construction difficulty. The result of this analysis was the establishment of the Long-list of pipeline corridor alternatives.
2	Long-list Alternative Analysis	Included a cost evaluation of the corridor alternatives, as well as an engineering evaluation of fatal flaw issues. The highest ranked alternatives were selected from the long list to create the Short-list of corridor alternatives.
3	Short-list Alternative Analysis	Included a conceptual level hydraulic analysis of each alternative, a non-cost evaluation of issues affecting project stakeholders, and a final ranking of the short-list alternatives. The result of this analysis was the selection of the highest overall ranked alternative as the final alignment corridor.

GIS as a Route Selection Tool

In general, GIS technology can be thought of as a way to attach information to graphics. A GIS may contain the same lines and symbols as a simple CAD drawing, but GIS allows data to be referenced to each graphical entity. This data is stored in a database, allowing the GIS user to sort and analyze this information in an infinite number of ways. GIS technology is ideally suited for a pipeline route selection study, because of the extremely large amount of data that must be managed for a project of this size.

In GIS, each graphical feature is related to a description contained in tables in a database. The collection of GIS data for the POMA route selection process involved a large amount of digital mapping of physical, political, and topological features. Examples of the type of data that was collected in GIS format include:

- Physical features such as roads, utilities, and canals.
- Political and demographic features such as city boundaries and land ownership parcels.
- Topologic or elevation data.
- Other features such as digital aerial photographs and seismic zones.

GIS was used as an engineering tool in this process by allowing the combination of various features in order to evaluate how one feature interacts with the others. For example, the utility map was combined with the POMA alignment map to aid in determining the amount of utility congestion that would be encountered within all segments of the proposed alignment.

Additional features of the GIS software allowed the analysis of the entire network of possible segments to quickly determine the optimum route between two points based upon cost, actual length, ease of construction, or any other factor. After each of the alignment alternatives were established, the GIS software was used to compare the length and associated costs of each route to allow a logical ranking of the alternatives, and ultimately narrow the study down to one final alignment.

LEVEL 1 – PIPELINE SEGMENT ANALYSIS

The first level of the pipeline route selection process involved the establishment of a study area and the analysis of all reasonable pipeline segments within this area. The pipeline segment analysis included the following tasks:

1. Define the boundaries of the project study area.

2. Identify all reasonable pipeline segments within this area.

3. Rate the segments with respect to cost, difficulty of construction, utility congestion, and other issues that would impact a decision to locate the POMA within each segment.

4. Develop a long list of pipeline route alternatives from this network of segments.

The following sections describe each of the tasks involved in the first level of the pipeline route selection process.

Definition of Study Area

The first task in the POMA route selection process was to define a study area that would establish the geographic boundaries of the project. The study area consists of a 30 square mile area that includes physical features from streams and parks to high groundwater areas and active fault zones.

Pipeline Segment Identification

Pipeline segments considered reasonable for the future POMA alignment were identified within the established study area. In general, segments included all possible corridors, both public and private, that were free of development. Pipeline segments that were identified for the POMA included public streets, open public and private rights-of-way, railroad corridors, canals, and future road corridors. The segments were identified in conjunction with MWDSLS personnel and input into the GIS.

The segments were divided to reflect lengths of pipe with similar features to allow each of the segments to be rated properly. Segments were divided each time a change occurred in surface condition or construction method. A total of 440 route segments were created for the POMA route selection process. These segments included more than 144 miles of streets and open right-of-ways.

Field Investigation

A field investigation was conducted to collect information for each of the 440 pipeline segments. The objective of the field investigation was to identify the physical features that may influence decisions to locate the pipeline within each segment. A standard form was created to assure that the same information was collected for each segment. Figure 1 provides an example of the form that was used for the field investigation.

Figure 1 – Example Field Data Sheet

Seg ID (#)	Location	Street Rating (1-7)	Street Width (ft)	Concrete Street? (y,n)	Driveway Access (1-3)	Utilities (1-3)	Crossing Type (1-6)	Crossing Length (ft)	Jack and Bore? (y,n)	Photo1 (ID#)	Photo2 (ID#)
1675	Newcastle Dr	6	55	n	1	3	NA	NA	NA	1758	0

Remarks and Notes

Quail Hollow Elementary School

Additional information documented for each segment included general observations, potential public and private disruptions, high ground water, and environmentally sensitive areas.

Identification of Fatal Flaws

Fatal flaws were identified to eliminate segments that were located in areas determined to be unacceptable for the POMA alignment. The project team identified fatal flaws following review of the physical features of the study area. Segments were considered fatally flawed if their location violated the primary objectives of the project, one of which is to provide a redundant water supply lifeline to the Salt Lake Valley in the event of a seismic event or other emergency.

Utility Investigation

The purpose of the utility investigation was to collect information on all underground utilities that may conflict with the pipeline alignment. Since the presence of underground utilities can significantly affect the cost of pipeline construction, this data was used to aid in the development of conceptual cost data for each pipeline segment.

Pipeline Cost Factors

Cost information was used for comparison purposes rather than for budgetary numbers in this first level of the route selection process. The objective of this analysis was to provide a method to rank various pipeline routes relative to cost.

Cost factors were developed for the various installation conditions that were observed during the field investigation. The cost factors were based upon an average pipeline installation condition that established the factor of 1.0. The unit cost associated with this average condition was estimated using recent pipeline bid tabulations and construction cost estimates.

Installation conditions that were determined to be more or less costly than the average condition were assigned factors greater than or less than 1.0. Variations from the average pipeline installation condition were categorized as follows:

1. **Urban Rating –** The type and traffic congestion associated with the street that the pipeline will be constructed.
2. **Utility Congestion Rating –** The amount of underground utilities that will potentially conflict with the pipeline during construction.
3. **Cathodic Protection –** The degree of protection the pipeline will require if constructed in a corrosive environment.
4. **ROW Width –** The available width of the pipeline construction area.
5. **Railroad Crossings –** The type of the railroad crossing; typically jack and bore construction.
6. **Groundwater –** The existence of a high groundwater table in the pipeline trench during construction.

The cost factors were used in the GIS model to assign equivalent lengths to each of the pipeline segments. The equivalent length is a cost-weighted length of pipe normalized to the average installation condition. For example, 100 feet of pipe jack and bored under the railroad (difficult conditions = cost factor of 2.82) may be equivalent in cost to 282 feet of pipe installed in a residential street (average conditions = cost factor of 1.0). Equivalent lengths were used to classify each segment according to cost of installation. The combination of segments between two points that generate the shortest equivalent length was considered the least cost alternative for the pipeline route.

The total cost factor for each segment was calculated by combining each of the six categories listed above. Factors were either added or multiplied together depending upon their relationship to the total cost of the installed pipe. An equivalent length for each segment was calculated by multiplying the total cost factor by the actual length of the segment.

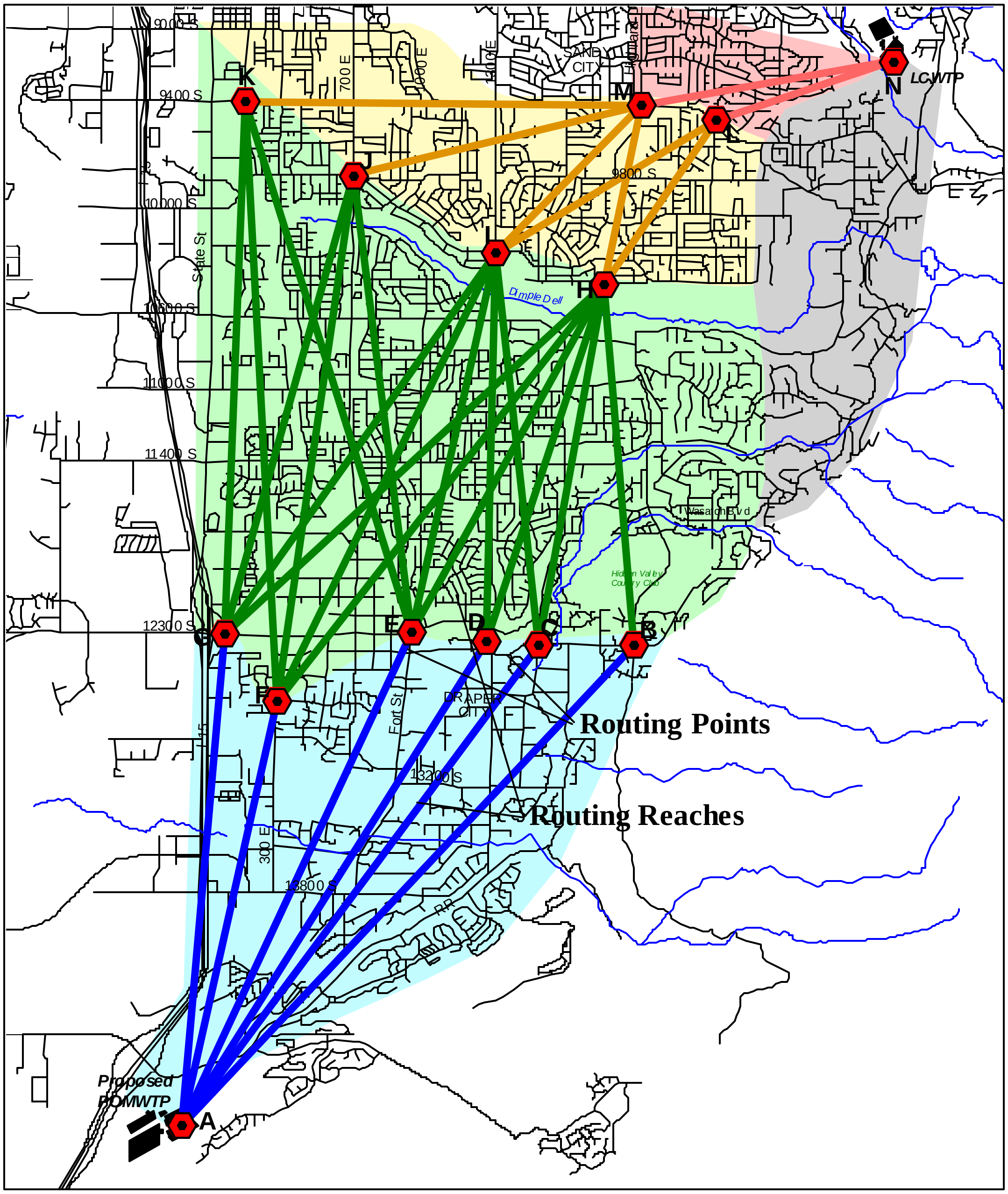
Development of Pipeline Corridor Alternatives

Pipeline corridor alternatives were developed following the assignment of equivalent lengths and elimination of fatal flaw segments from the study area. The challenge of creating alternatives from the limitless number of segment combinations required a logical process. It was understood that the list of alternatives were required to represent all reasonable corridors available for the POMA within the study area. To accomplish this, the study area was divided into four separate regions, called reaches.

The boundaries between reaches were defined by areas of congested development that appeared to force the pipeline through only a few points along the boundary. These points were defined as routing points for the POMA. The routing points between each reach were connected with straight lines to establish the combinations of alignment corridors that were available for POMA.

The routing points allowed the evaluation of each of the shorter corridors between points rather than an evaluation of the full-length corridor between the two treatment plants. The best corridors between each of the routing points were then joined together in the 28 established combinations to create the long list of alternatives from the POMWTP to the LCWTP. Figure 2 illustrates the development of routing reaches and routing points for the POMA route selection.

Figure 2: Routing Points and Routing Reaches



LEVEL 2 – LONG LIST ALTERNATIVE ANALYSIS

The 28 combinations of pipeline corridors that were developed in the first level of the analysis created the long list of alternatives for the POMA. The second level of the route selection process involved the evaluation of these alternatives considering both cost and non-cost issues. The long list alternative analysis involved the following tasks:

1. Develop long list of pipeline routes.
2. Rank the long-list alternatives relative to cost.
3. Short list the top ranked alignments for further evaluation.

Develop Long List of Pipeline Routes

The first level of the route selection process identified 28 combinations of pipeline corridors that were possible. These combinations were defined by straight-line connections between the routing points. The next step of the long-list alternative analysis required that these straight-line combinations be converted into actual pipeline routes. These routes were developed using a network analysis software package in the GIS system. This tool was used to model all of the data that was gathered for each of the 440 segments in order to develop the least cost path between points within the study area.

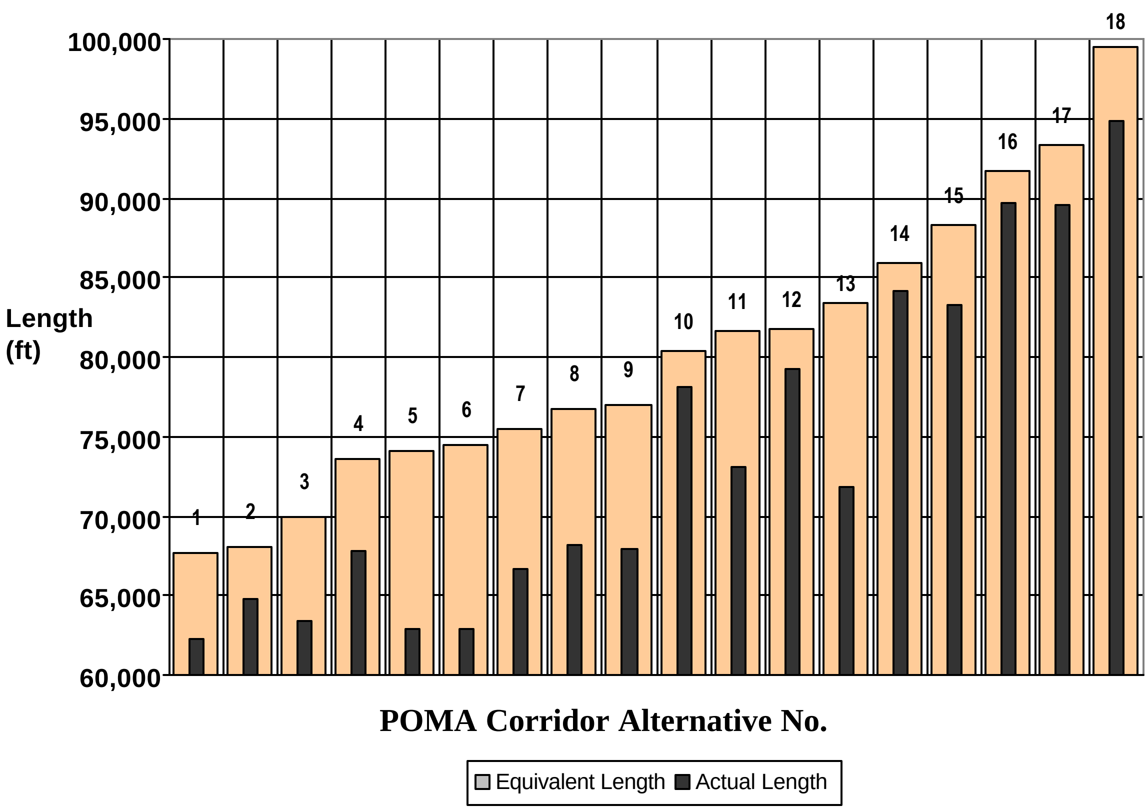
The network analysis software was used to model the least cost path between the established routing points. The 28 long-list pipeline alternatives were established using this process. It should be noted that no engineering analysis of the routes had been considered to this point. The model was used to develop the least cost alternatives between the routing points.

Alternative Evaluation

The objective of the long-list alternative evaluation was to rank each of the alternatives in order to identify a short list of potential routes for a more detailed evaluation. The purpose was not to identify reasons to eliminate alternatives from the long list, but instead was to select a short list of alternatives for further evaluation. It was understood that the remaining group of long-list alternatives would be considered if the further evaluation of the top alignments revealed hidden flaws in these alternatives.

The alternatives were ranked based upon the equivalent lengths of each route. As stated previously, the pipeline route with the shortest equivalent length was considered the lowest cost alternative. Figure 3 provides a summary of the long-list alternatives ranked from shortest to longest equivalent length. The actual length of each of these alternatives is also included in this graph for reference.

Figure 3 – Actual and Equivalent Lengths of Long-list Alternatives



Note that the top ranked alternative based upon equivalent length (least cost) is also the shortest alignment between the two treatment plants. Rankings varied slightly on alternatives that were located in areas that tended to skew the equivalent length due to higher or lower cost of construction. The fact that the equivalent and actual length rankings are relatively close is evidence that the cost factors were not drastically skewing the results of the analysis.

An evaluation was performed on the ranked list of alternatives. The goal of the evaluation was to develop a short list of approximately five alignments that would satisfy the objectives of the project. The evaluation included a review of cost issues, non-cost issues, and engineering related issues, all of which would be further refined during the short-list alternative evaluation.

Based upon review of these issues, a recommendation was made to shortlist five of the eighteen long-list alternatives. The five alternatives included numbers 1, 2, 3, 5, and 6. The project team agreed that these five alternatives required further evaluation, because they represented the apparent shortest length and least cost routes between the two treatment plants. They also each appeared to satisfy the non-cost and general engineering objectives of the project. The remaining thirteen alternatives were reserved in case flaws were discovered with any of the five short-listed alternatives following the further analysis.

LEVEL 3 – SHORT-LIST ALTERNATIVE ANALYSIS

The purpose of the short-list alternative analysis was to evaluate each of the alternatives with respect to hydraulic performance, overall cost, non-cost issues, and general compatibility with the requirements of the project. The short-list analysis involved the following tasks:

1. Perform a general hydraulic analysis on each of the alternatives.
2. Evaluate the alternatives according to cost.
3. Evaluate the alternatives according to non-cost issues.
4. Recommend a final alignment corridor for the POMA.

Hydraulic Analysis

A general hydraulic analysis was performed for each of the five short-listed alignments. The purpose for the hydraulic analysis was to identify the hydraulic differences between the short-list alternatives, and to identify any potentially negative hydraulic aspects of each of the corridors.

The results of the hydraulic analysis indicated that the short list of corridor alternatives did not vary significantly with respect to hydraulics. Results of this hydraulic analysis confirmed that each of the short-listed alternatives could serve as viable routes for the POMA.

Short-List Cost Evaluation

The five short-listed alternatives were ranked based upon their estimated costs of installation. The costs used in the ranking were based on the pipeline lengths and diameters and pump sizes calculated in the hydraulic analysis. Costs for the pipeline alignments were calculated based on the cost factors developed in the first level of the route evaluation process.

Alternative numbers one and two were determined to be the lowest cost routes. Both alternatives are located within generally open corridors. These two areas are preferred because of the lack of utility congestion and minimal surface improvements associated with these open rights-of-way.

Short-List Non-Cost Evaluation

The project team understood that a number of issues not related to cost would impact the selection of a final route for the POMA. Construction of the POMA will impact traffic control and will disrupt public services. It will largely impact adjacent communities and businesses along the entire alignment. There will be permit issues to resolve, environmental concerns to address, and seismic considerations to understand. The location of the aqueduct will impact MWDSLS O&M staff for the lifetime of the project. Many of these potential problems are not addressed by cost factors alone, making the evaluation of non-cost issues an important part of the short-list alternative analysis. Nine categories of non-cost issues were identified for the project. These categories are summarized in Table 3.

A survey was created and distributed to each of the project stakeholders following the development of these non-cost categories. The project stakeholders included cities, counties, and agencies that would be impacted by the project. The intent of this survey was to allow the stakeholders to provide critical input during the POMA route selection process.

A rating system was set up for each of the non-cost categories. Each pipeline segment in the short-list of alternatives was rated according to the nine non-cost categories. A value of one to five was assigned to each segment, with one being the least favorable and five the most favorable. This information was included in the analysis in order to understand the relative importance of the various non-cost categories to each alternative. Factors were normalized with respect to length of each segment so that a very low scoring but short segment would not skew a higher scoring longer section. The non-cost ratings were developed based upon field investigation data and GIS information such as aerial photographs, zoning maps, seismic zones, canals/streams, hospitals, schools, and parks.

A weighting factor was used to classify each category according to its relative importance in the non-cost evaluation. The weighting factors were based on direct input from POMA stakeholders during coordination meetings, and from results of the non-cost factor survey that was completed during the long-list evaluation.

According to the results of the non-cost scoring, alternatives 2 and 3 were ranked the best according to the non-cost issues that were evaluated. The total non-cost scores were very close between the first three alternatives, showing that they are all relatively equal corridors from a non-cost standpoint.

Table 3 – Non-Cost Issues Considered for POMA Route Selection Process

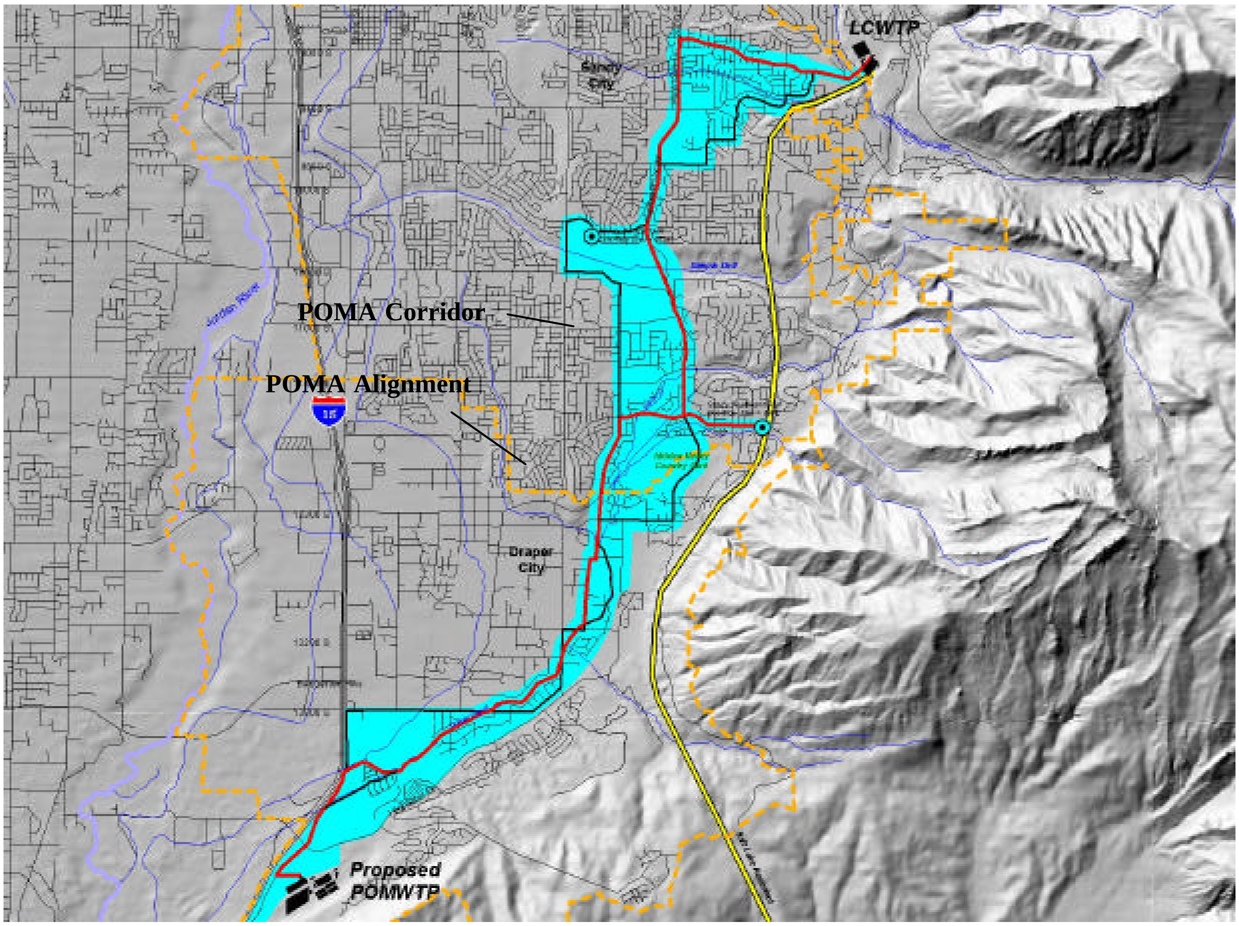
Non-Cost Issue	Description
Constructability	Constructability addresses the ability for the contractor to construct the pipeline in a timely manner without excessive interference from physical obstacles. These physical obstacles could include narrow ROW, limited site access, limited staging area, steep terrain/slope, deep trench conditions, or other undesirable surface conditions.
System Compatibility	System Compatibility addresses the requirement for the alternative to perform its proper function in the POMA transmission system. This includes proximity to preferred delivery points, general hydraulic compatibility, and ease of O&M.
Community Disruption	Community Disruption addresses the impact that the pipeline alterative will have on the local community. This includes the impact during construction on residential areas, commercial access, access to and from public facilities, and emergency services disruption. This category also includes the impacts on the community following pipeline construction.
Traffic and Transportation	Traffic and Transportation addresses the non-cost traffic impacts that the pipeline construction may have on the local community. This category includes negative impacts created by limiting access on key roads, or disrupting public transportation.
Utility Conflicts	Utility Conflicts addresses the non-cost related impacts of utility conflicts with the pipeline alignment. This includes the disruption of utility services, lengthy coordination with utility companies, or relocation of utilities. This category also includes the possible negative impact of the pipeline on future access to adjacent utilities and utility crossings.
Seismic and Geologic Considerations	Seismic and Geologic Considerations takes into account the seismic activity around the pipeline corridor, including potential liquefaction zones and fault lines. Other geologic considerations include corrosive soils, rocky conditions, or required special trenching techniques.
Environmental Concerns	Environmental Concerns addresses the environmental sensitivity of the areas along and around the proposed alignment.
Permit Issues	Permit Issues addresses the possible need for any special permits required by crossing, encroaching, or otherwise impacting the surrounding area.
ROW Issues & Land Use	ROW Issues & Land Use addresses the possible need for easement or ROW acquisition along the pipeline alignment and possible negative land use changes over the pipeline corridor.

Final Pipeline Corridor Recommendation

Results of the short-list alternative evaluation indicated that Alternative No. 2 ranked the best according to cost, and Alternative Nos. 2 and 3 ranked highest relative to non-cost issues. Following a review of the alternatives by the project team, all agreed that each of the top three alternatives would serve as excellent routes for the POMA.

A decision was made to establish a wide final alignment corridor for the POMA that includes the short-list alignment numbers one and two, with variations of number three included. This corridor includes a recommended alignment with options to allow for flexibility during preliminary and final design. Alignment options were preserved into the final design process to allow for changes that may occur because of utility conflicts, community issues, political pressures, etc. Figure 4 provides an illustration of the recommended POMA final alignment corridor.

Figure 4: POMA Final Alignment Corridor



The POMA final alignment is now in the final design phase and will soon begin construction. The POMA final alignment shown in Figure 4 has gone through numerous engineering and cost evaluations, community comment periods, and political scrutiny, and through all this, the selected final alignment has not changed significantly. A route selection process that is well documented, uses the best available data, and allows early input from stake holders will in the end save in design costs and hold up under last minute criticism.

References

[i] "A Versatile Route Selection Process", Phillip K. Ryan, CH2M Hill, presented at the 2001 ASCE Pipelines Conference.

[ii] "Pipeline route Selection for Rural and Cross-Country Pipelines:, ASCE Manuals and Reports on Engineering Practice No. 46, 1998.