EVALUATION OF QUANTM SOFTWARE FINAL REPORT

Report No. CDOT-DTD-E-2006-1

CARTER AND BURGESS, INC.

DEPARTMENT OF TRANSPORTATION RESEARCH

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16. Abstract

The Colorado Department of Transportation (CDOT), Department of Transportation Development (DTD) conducted a study to evaluate the usefulness of the Quantm system for planning transportation improvements in Colorado. The Quantm system includes proprietary route optimization software that can be used to develop and screen transportation improvement alternatives. For this study, the project team performed the evaluation by applying the system to data from an on-going CDOT Environmental Impact Study (EIS) project in the Denver Metropolitan Area. It is important to note that the sole purpose for this study is to evaluate the usefulness of the Quantm software for CDOT, and not to influence or affect the case study project in any way. The study team investigated the use of Quantm both with data commonly available prior to the commencement of the EIS process and with data that were developed as a result of the EIS process. A cost/benefit analysis was also performed.

The results of the study found that Quantm can provide significant benefits to CDOT projects that have at least one of the following characteristics: 1) an opportunity to optimize cut/fill to save construction costs, or 2) an opportunity to develop new alignments that do not strictly follow an existing route. Additional indicators for projects that might benefit from using the Quantm system are included in the results. The study found that when construction cost savings are taken into account, the financial benefits of Quantm have the potential to far outweigh the costs of using the system. The study outlined the major data sets that are needed for a successful Quantm implementation, and concluded that Pre-NEPA data are sufficient to begin using the system on a project.

Implementation:
The study report can be used by CDOT and its consultants to assist in determining whether to employ the Quantm system on transportation planning and design projects in Colorado.

17. Keywords	18. Distribution Statement
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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

The Colorado Department of Transportation (CDOT), Department of Transportation Development (DTD) conducted a study to evaluate the usefulness of the Quantm system for planning transportation improvements in Colorado. The Quantm system includes proprietary route optimization software that can be used to develop and screen transportation improvement alternatives.

For this study, the project team performed the evaluation by applying the system to data from the Northwest Corridor (NWC) Environmental Impact Statement (EIS), an on-going CDOT NEPA project in the Denver Metropolitan Area. It is important to note that the sole purpose for this study is to evaluate the usefulness of the Quantm software for CDOT, and not to influence or affect the NWC project in any way. This report refers to the NWC project as the Case Study project.

The scope of the study includes seven tasks. Task 1 consists of project management throughout the project. Task 2 is to gather the case study data and to understand the data collection and translation requirements necessary to apply the Quantm software package. For the third task, the study team attended and evaluated the training provided by Quantm in order to assess the quality of the training and to recommend training requirements for future projects involving the software. In Tasks 4 and 5, the study team evaluated the Quantm alignment development process under two scenarios: 1) using data available at the beginning of an EIS project, or "pre-NEPA" (Task 4), and 2) using the data developed during the course of a NEPA project (Task 5). Following evaluation of the pre-NEPA and NEPA scenarios, Task 6 of the study evaluated level-of-effort differences in terms of cost between current alignment development processes and those involving the Quantm system. Task 7 involves bringing the results of the previous tasks together into this Final Report.

Based on our study, Quantm can provide significant benefits to projects that have at least one of the following characteristics:

- An opportunity to optimize cut/fill to save construction costs
- An opportunity to develop new alignments that do not strictly follow an existing route

For projects that meet at least one of the above two criteria, the following criteria represent additional indicators that Quantm is well-suited for the project:

- Significant portions of the project include rolling or hilly terrain
- Significant portions of the project may require new roadway alignments or major realignment
- Significant portions of the project are in non-urban areas
- There is a need to investigate all realistic alternative alignments, including new routes
- A project goal is to reduce construction costs by optimizing the vertical and/or horizontal alignment
- The project alignment will be affected by complex environmental and/or social constraints

In general, the following project characteristics are indicators that a project may not benefit from Quantm:

- Projects that are upgrades or repairs to existing roadways (i.e. little change to the vertical or horizontal alignment)
- Projects that are highly constrained in the vertical by intersections and in the horizontal by right-of-way availability
- Projects that are short in length (< 2 miles)
- Projects that are entirely urban
- Projects that are located in relatively flat terrain

We estimated that it would have cost about $308,000 to implement Quantm on the Case Study project and that it would have provided about $234,000 in efficiencies to the project (for a net cost of $74,000), not including any savings that could be realized during construction. Although construction cost savings cannot be accurately calculated for the Case Study project, Quantm provided optimized routes that calculated potential savings in the range of 6% - 29% for Vertical Optimizations to over 40% for other Refinement Optimizations if/where some horizontal movement is possible (Section 5.5.2.2). Because every 1% savings in construction costs represents on the order of $4 million, the potential benefit in reduced construction costs greatly outweighs the net investment in the system. Therefore, our analysis shows that Quantm is very cost effective when applied to projects of a similar nature as the Case Study.

As part of the cost/benefit analysis (Section 6), we conducted a literature review of other studies that have used Quantm. These other studies also indicate that Quantm is generally cost effective for planning projects and that it reduces estimated construction costs.

Because the Quantm system works within the framework of the NEPA process, and because the cost of the system is on a per-project basis, the best time to apply the software is early in a project, prior to the development of alternative routes. However, the literature includes projects in which Quantm was brought into a project once the NEPA process was well underway and used with good results. Also, because of the optimization capabilities of the software, we believe that Quantm can be used successfully in the design phase of a project that is in rough or rolling terrain.

Overall, the study team found that a large volume of highly-developed data is not necessary at the beginning of a project that incorporates the Quantm process. The nature of the NEPA process is to move from a large number of possible alignments to a small number of alignments through a process of elimination. At the beginning of the NEPA process, Quantm can be best used to develop a broad range of possible alignments when the system has fewer constraints (particularly fewer avoidance areas). The study team has found that the Pre-NEPA data layers that are key to the successful use of Quantm at the beginning of a project are:

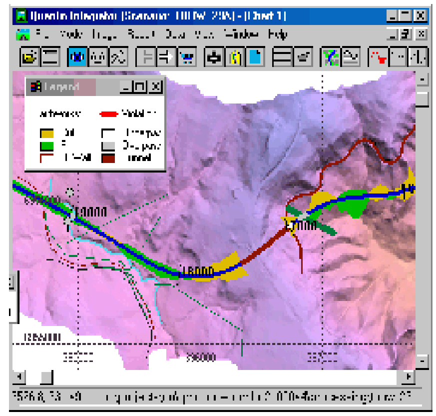
1. Digital Elevation Model
2. Engineering Parameters
3. Aerial Photography

4. Base map
5. “Absolute” or “Hard” Avoidance Areas
6. Land Use

Data layers developed during the NEPA process are needed to refine alignments and to compare routes in terms of cost and environmental and social impact. However, the initial development of alternative alignments to be investigated can be performed with Pre-NEPA data as described above. As the project progresses, incremental improvements to engineering parameters and GIS data can be reflected in the Quantm system.

2.0 INTRODUCTION

Planning multi-modal transportation improvements at an early stage is critical for agencies seeking to meet the current and future demands for their transportation infrastructure. Rising demands, fiscal constraints, and increased public awareness has lead to the need for more tools to assist transportation planners in evaluating engineering and National Environmental Policy Act (NEPA) constraints before projects are funded for detailed evaluation. To facilitate the understanding and use of such tools, the Colorado Department of Transportation (CDOT), Department of Transportation Development (DTD) is conducting a study to evaluate the usefulness of a roadway (and railroad) alignment development system called Quantm for planning transportation improvements in Colorado.



The Quantm system (Quantm Ltd.: www.quantm.net) involves proprietary route optimization software that can be used to develop and screen transportation improvement alignments. The system is licensed by Quantm Ltd. on a project-by-project basis, and includes use of the software throughout the project, in-house training for the project user group, and support by their in-house team of professionals.

Quantm uses the Internet to enable project planners to use the Quantm software from their desktop PC (using Quantm Integrator) while the bulk of the computing work is performed by the optimization engine (Quantm Pathfinder) in the Quantm offices. It also allows Quantm's Technical Support Engineers to monitor optimization runs and to provide ongoing support. Appendix A contains a more detailed overview of the Quantm system.

2.1 Overall Project Scope

Study Tasks:

1. **Project Management**
2. **Data Collection and Translation**
3. **Attend/Evaluate Quantm Software Training**
4. **Evaluate Pre-NEPA Alternatives Development**
5. **Evaluate NEPA Alternatives Development**
6. **Conduct Cost Comparison**
7. **Prepare Final Evaluation Documentation**

The primary purpose of this study was to evaluate the usefulness of the Quantm system for planning transportation improvements in Colorado. For this study, the project team performed the evaluation by applying the system to data from the Northwest Corridor (NWC) Environmental Impact Statement (EIS), an on-going CDOT NEPA project in the Denver Metropolitan Area. The NWC EIS was selected by CDOT because it includes both urban areas where alignments would tend to follow existing roadways and rural areas where new sections of roadway may be needed. A description of the case study project is included as Appendix B of this report. It is important to note that the sole purpose for this study is to evaluate the usefulness of the Quantm software for CDOT, and not to influence or affect the NWC project in any way. Henceforth, this report will refer to the project as the Case Study project.

The scope of the study includes seven tasks. Task 1 consists of project management throughout the project. Task 2 is to gather the case study data and to understand the data collection and translation requirements necessary to apply the Quantm software package. For the third task, the study team attended and evaluated the training provided by Quantm in order to assess the quality of the training and to recommend training requirements for future projects involving the software. In Tasks 4 and 5, the study team evaluated the Quantm alignment development process under two scenarios: 1) using data available at the beginning of an EIS project, or "pre-NEPA" (Task 4), and 2) using the data developed during the course of a NEPA project (Task 5). Following evaluation of the pre-NEPA and NEPA scenarios, Task 6 of the study evaluated level-of-effort differences in terms of cost between current EIS processes and those involving the Quantm system. Task 7 involves bringing the results of the previous tasks together into this Final Report.

Questions to be answered in this final report include:

- Can the Quantm software provide a significant benefit when used in planning transportation improvements in Colorado?
- When in the process should the software be applied to provide maximum benefit?
- How are transportation improvement alignments developed and evaluated using Quantm?
- What are the critical data needs for using Quantm?
- In terms of cost, how does the Quantm process compare to existing EIS processes?
- How does the Quantm process address other modal alternatives?

Section 7 of this report addresses these questions.

2.2 General Description of the Quantm Process

The Quantm Integrator User Manual describes the Quantm system as: *…a planning tool that uses state-of-the-art computer techniques to automatically generate low-cost planning alignments that satisfy defined constraints. It consists of two distinct pieces of software:*

- ***Quantm Integrator****, which resides on the client's PC and is used to define scenarios and review results of optimization, and*

- ***Quantm Pathfinder****, which resides on powerful computers at Quantm's offices and provides the necessary power to run the optimizations.*

  The Quantm system generates sets of alternatives, rather than a single least-cost solution, to allow planners the freedom to balance environmental and social impacts against costs for routes using different parts of the corridor and various scenarios of cost structures and constraints.

Baseline data sets are input into Quantm Pathfinder and made available in Quantm Integrator, along with engineering parameters, linear features and special zones. Quantm organizes the different types of data into individual data files, which the study team then puts together in Quantm Integrator in various combinations or "scenarios." These scenarios are then sent via e-mail to Quantm Pathfinder, and Pathfinder uses the scenarios to generate sets of possible alignments. Pathfinder can analyze scenarios in a number of ways, including "unseeded" runs that return a wide variety of geographically distinct routes that satisfy the project constraints, and "seeded" runs which focus on a particular route for optimization. From each unseeded scenario run, Quantm Pathfinder returns 50 alignments, while seeded scenario runs return 20 alignments.

The study team conducted sensitivity analyses with various parameters and optimization runs for individual alignments in order to better understand the Quantm system and the effects of various parameters on the results. The following section describes the data inputs used in preparing Quantm scenarios.

2.2.1 *Input Data Sets*

2.2.1.1 Terrain

The Quantm system uses a terrain model as the basis for its engineering computations, so elevation data must be provided at the beginning of any Quantm project. Because of their wide availability and low cost, USGS digital elevation models (DEMs) are frequently used during the early stages of a project (though higher-resolution data should be used if available for the project). USGS DEMs are available for the entirety of Colorado at no charge through the USGS web site (www.usgs.gov). These DEMs provide a horizontal resolution of 30 meters or better and are therefore suitable for planning exercises. Once the DEM is submitted to Quantm, the model is used to calculate cut and fill and to guide the development of alignments along the existing terrain.

The Quantm system can also utilize DEMs created from satellite or aerial imaging where horizontal resolution can be < 1 m.

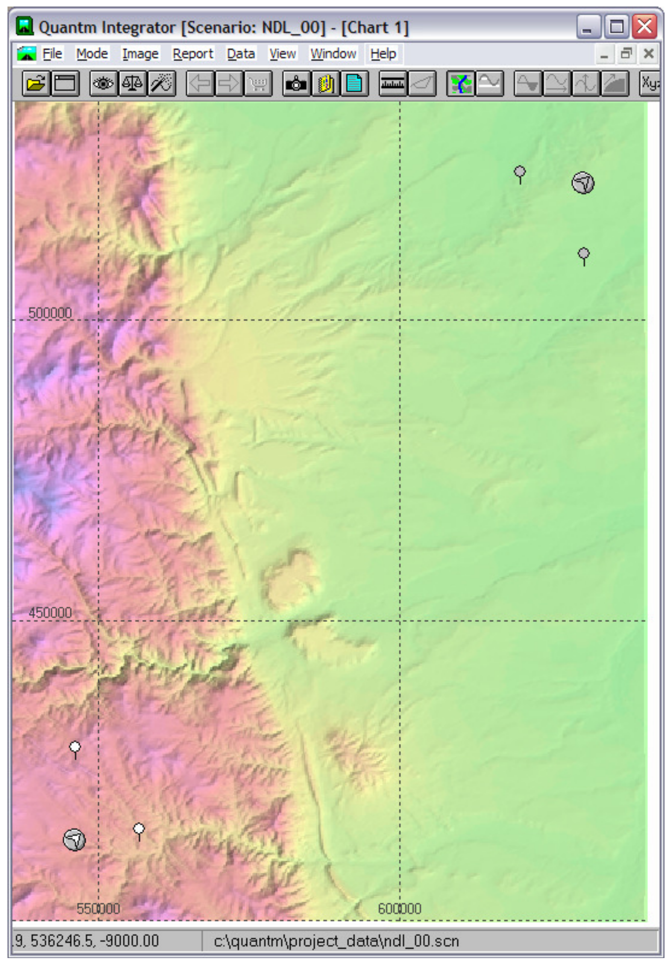


Figure 1: USGS DEM as Depicted by Quantm Integrator

Figure 1 depicts the Pre-NEPA terrain model as a layer in Quantm Integrator once it has been converted to the Quantm format.

For the NEPA phase of the Quantm evaluation, the USGS DEM was replaced with a high-resolution DEM generated from aerial photography for the project study area.

2.2.1.2 Imagery

Quantm also allows for digital imagery to be used as a background layer for reference purposes. Surface images may be obtained from satellite imagery (such as sold by Space Imaging or Digital Globe) or from aerial photography (such as the USGS orthophotos) and then converted to Quantm's native format. For this study, an aerial photograph of the project area was obtained from the Case Study project for use as a background image in the Quantm analysis (Figure 2).

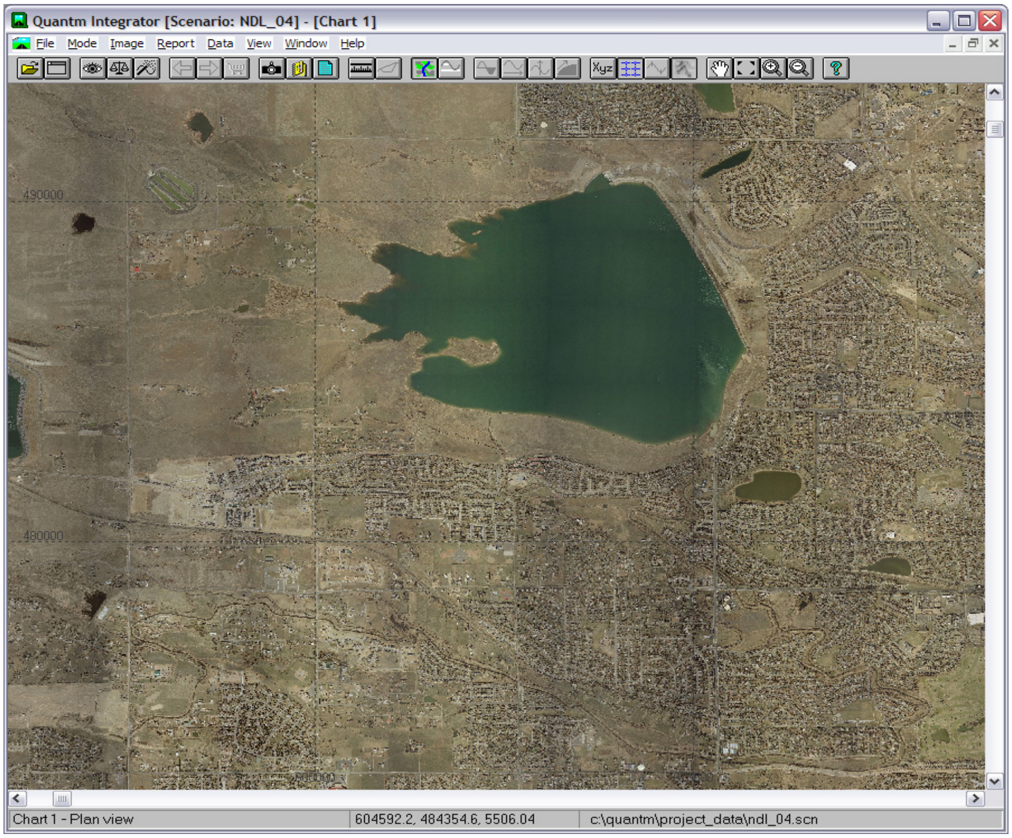


Figure 2:
Portion of the Aerial Photograph Depicted by Quantm Integrator

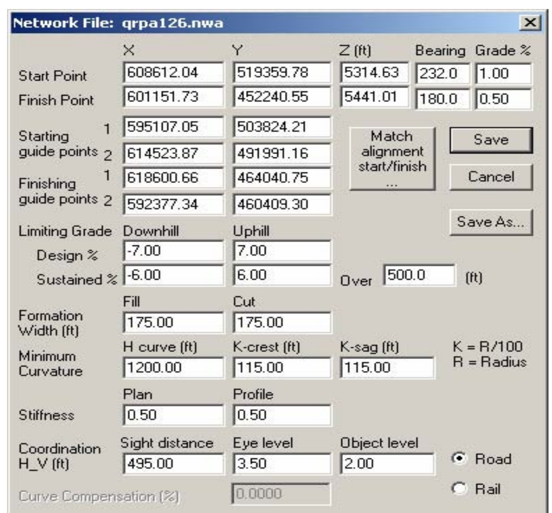
Although digital imagery is not a necessity and the Quantm system itself does not rely on it directly in any way, it can be very helpful to assist in identifying features and displaying the region(s) impacted by the various alignment options being considered.

2.2.1.3 Engineering Parameters

Engineering parameters used by Quantm include geometric parameters, geologic data, and costs. Engineering parameters in Quantm are entered directly into the Integrator software and saved in their own data files. To facilitate the collection of engineering parameters, Quantm provides a data form (Quantm Data Input Requirements questionnaire) that can be printed and filled out by project engineers prior to implementation of the Quantm application.

The Case Study project is considering a range of roadway facility types and speeds including arterial (55 mph design speed), freeway (60 mph), tollway (60 mph), arterial with light rail (55 mph), arterial with bus rapid transit (55 mph), tollway with light rail (60 mph) and freeway with bus rapid transit (50 mph). The main differences between these alignments that are recognized by Quantm input parameters are width and curvature, although other projects may also consider different maximum grade criteria, especially when considering different modes of transportation. These parameters were entered into the Quantm data forms and then converted for use in scenarios. Quantm does not consider the specific needs of multi-modal transportation alignments as part of a single scenario evaluation. Therefore, the NEPA analysis considered the 55-mph arterial as the basis for all its scenarios since it provides an average width and curvature requirement.

The engineering data required by Quantm was obtained from roadway design criteria provided by the Case Study design team, and cost information was obtained from CDOT cost data and similar projects in the metro area. The following is a list of the engineering data Quantm requires.

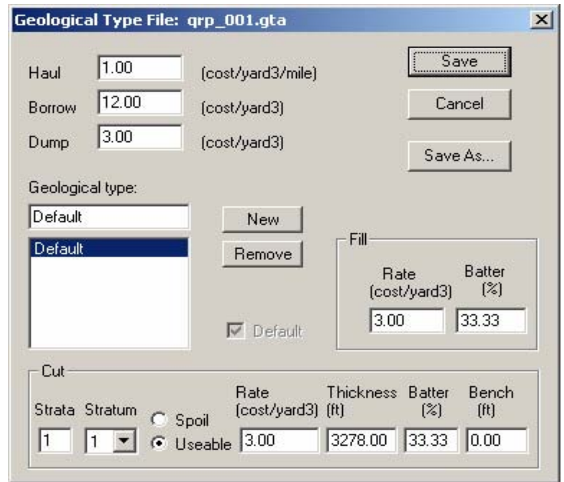


Network. The network data file is used to establish the start and finish points and define the geometric and engineering criteria, horizontally and vertically. The following are required input:

1. A start point and finish point are located with coordinates as well as bearing (azimuth) and grade.
2. ‘Guide posts’ are located between the start and finish points to help define the search area for alignments. These are also located by coordinates.
3. Maximum grades and sustained grade.
4. The formation width or template. For this project the width used was back of walk to back of walk for the arterial section and z-slope to z-slope for the freeway and tollway section.
5. Minimum curvature defines the horizontal curves by radius and the vertical curves by crest and sag K values.

6. Stiffness is a value that Quantm uses to control the number of curves along an alignment whilst still adhering to the minimum curve criteria. It is a proxy for rate of change of curvature. Values from 0 to 1 are input, with 0 being a large number of curves allowed and 1 being very few curves allowed.

7. Horizontal/Vertical coordination is a roadway sight distance value that includes eye height and object height. It uses a reaction sight distance criteria as a mechanism for coordinating horizontal and vertical geometry for road projects.



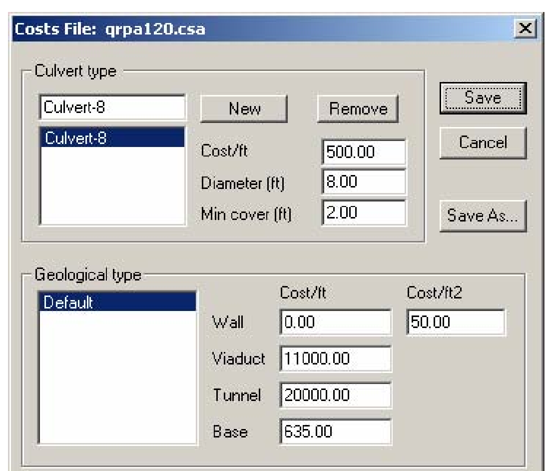
The start point for all of the study scenarios was in the northern portion of the study area, at the western end of the Northwest Parkway, near US 36 and Storage Tek Drive. The existing roadway network at the south end of the Case Study project area creates at least two distinctly separate termination areas for potential roadway alignments. Alignments considered for the central to western portion of the study area would logically terminate near the Interstate 70 (I-70)/C-470 interchange because of urban land use issues and terrain (North and South Table Mountains). Likewise, alignments considered for the central to eastern portion of the study area would logically terminate near the I-70 and State Highway 58 (SH 58) interchange to take advantage of the existing roadway network. Because Quantm can only consider one start and one finish point for each scenario, the evaluation team created two separate case studies, a West-Side case and an East-Side case.

> ***Two geographic case studies were developed for the Quantm analysis:***
>
> ✓ **West-Side** case study terminating at I-70/C-470
> ✓ **East-Side** case study terminating at I-70/SH 58.

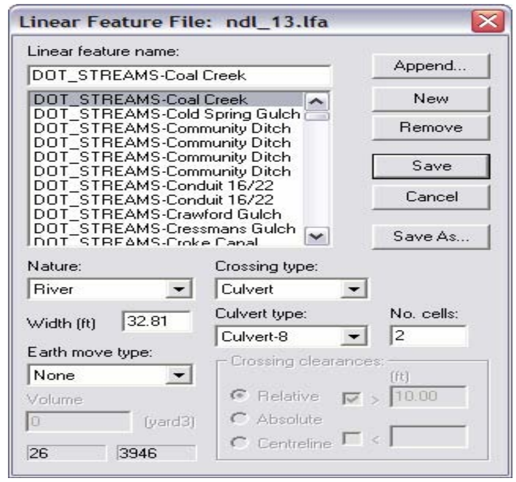
Geological Type. This data includes earthwork costs and cut and fill slope percentages for different soil strata. For this study a default type was used for the entire project area. Some costs were adjusted as better data was received from the Case Study study.

Geological Zone. This option defines the geographical boundaries of each geological type within the study area. As only one (default) geological type was considered for this project, no geological zones were necessary.

Costs. The cost file identifies costs for culverts, bridges, tunnels, retaining walls and roadway pavement material. Costs are entered as a linear foot or square foot unit and can vary with soil (geological) type and depth.



These sets of data are completed for each type of roadway facility (e.g. freeway) and submitted to Quantm Pathfinder based on the scenario desired. The vertical grades, formation width, curvature and sight distance can be varied depending on the type (arterial, highway, etc.) and design speed of the facility.



2.2.1.4 Linear Features

In the Quantm system, linear features can be used to provide a base map reference and to delineate features that must be crossed in some way (and at some cost) by the alignment. In Quantm, all linear features are maintained in a single layer and identified individually by name. These features are developed in GIS or CAD by the study team, with a special 'Quantm' field defined that contains the name or identifier for the feature. The shapefile is submitted to Quantm for conversion to Quantm format, and returned to the study team as a data file that can be adjusted and used in scenarios (Figure 3). For each scenario, the nature of each linear feature is defined by the user (road, river, railway, other, ignored), as well as the type of crossing that would be required if the alignment were to cross the feature. For example, rivers may require a culvert or bridge crossing, and roads and railroads may require grade separations (or that the alignment cross at grade).

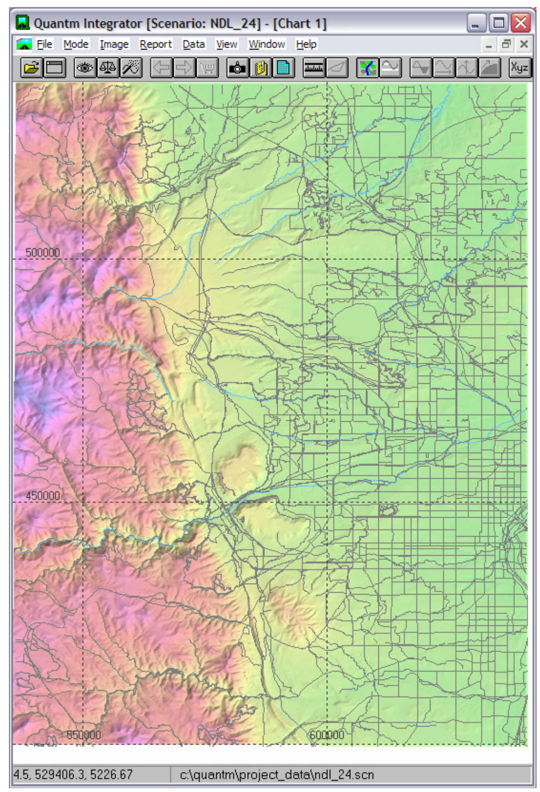


**Figure 3:
Linear Features (Roads, Trails, and Streams) in the Quantm Integrator**

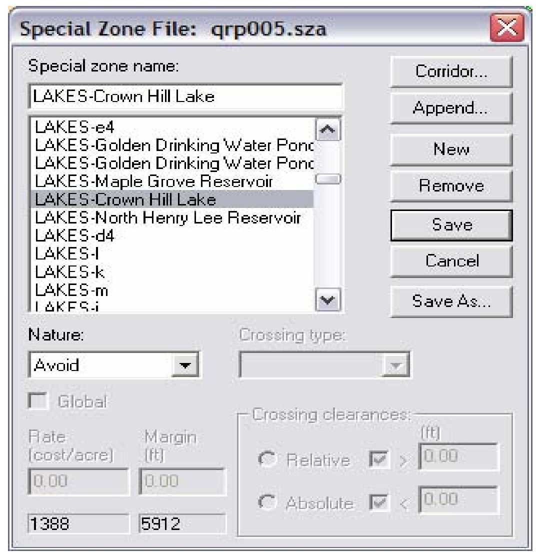
Linear features are not used in Quantm to guide unseeded alignment development. That is, alignments generated by Quantm will not favor existing roadways that are defined by linear features. However, they can be used as a basis for realignment optimization runs to develop cut and fill quantities and cost when the study team wants to optimize a particular existing alignment that may require realignment to a higher engineering standard. The existing linear feature (i.e. existing road) can be defined as the basis of optimization, and alternatives will only depart from this alignment where the geometry is deficient or avoid areas preclude this option.

In unseeded runs, changes to the nature of the linear features appeared to affect the cost and profile of alignments, but not their locations. In Quantm, only special zones can be used to identify avoidance areas.

Using basemap data from the Case Study project, the study team developed a set of linear features that included streams and rivers, roadway centerlines, railroads, and trails. Because the focus of the Pre-NEPA evaluation was on the generation of usable corridors in the plan view, with less focus on cost and vertical considerations, linear features were used most often as a map reference. For the NEPA phase of the evaluation, linear features were used to define key grade separations only for the engineering optimization runs.

2.2.1.5 Special Zones

Along with linear features, special zones can also be defined in Quantm to delineate an area that requires special treatment. Special zones are the method whereby avoidance areas are delineated, and they are also used to describe areas where special crossings such as a tunnel, bridge or vertical clearance (such as a floodplain) would be required. Special zones may also be used to indicate areas that carry additional costs when crossed by an alignment, due to such factors as high property costs, relocation costs, or costs for mitigation.



As with linear features, special zones are maintained in a single layer and identified individually by name. Special zones can be created from polygon shapefiles, or they can be digitized directly into Integrator. For each individual special zone, the nature of the feature is selected (e.g. avoid, water, extra cost, earthwork limits, other, ignored), as well as the special consideration that the model should give to the zone. In the case of avoidance zones, the model will make every attempt to avoid impacting the zone altogether, and will never pass through the center of the zone. Because the user has to set parameters for every polygon with a distinct value, fewer polygons result in greater ease in managing the data. An example of special zones is depicted in Figure 4.

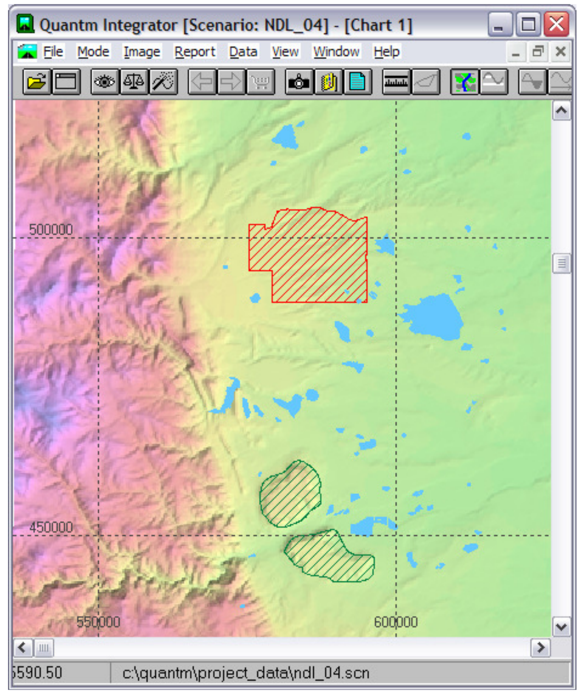
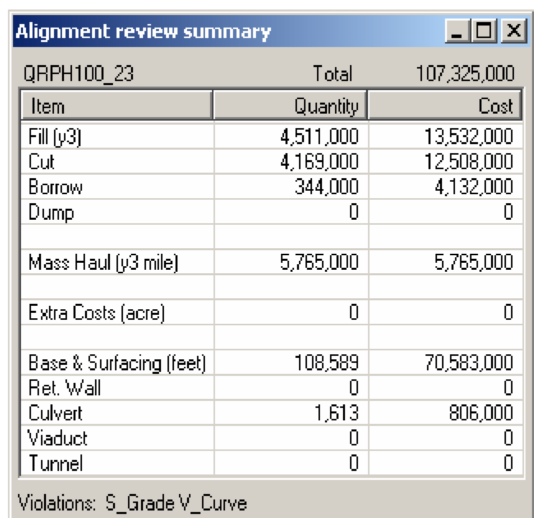


Figure 4:
Example of Special Zones (red=avoid, blue=water, green=tunnel)

2.2.2 *Output Data Sets*

Quantm returns fifty (50) or twenty (20) alignments for each set of data submitted as described in Section 2.2. Data returned or available for each alignment includes:

- Plan and profile geometry, including curvature and gradient information
- Extent of earthworks
- Volumes of cut, fill, borrow, and dump
- Locations and quantities of special structures needed (e.g. tunnels, retaining walls, culverts)
- Baseline or Alignment construction cost estimate, including a breakdown of Extra Cost areas impacted and detailed by quantity (impacted area) and cost (additional land treatment, ROW, mitigation or other)
- Locations and values for violations of the defined constraints (including engineering parameters or linear features) and special zone constraints (such as vertical crossing clearances)



Alignment review summary

QRPH100_23   Total   107,325,000

Item	Quantity	Cost
Fill (y3)	4,511,000	13,532,000
Cut	4,169,000	12,508,000
Borrow	344,000	4,132,000
Dump	0	0
Mass Haul (y3 mile)	5,765,000	5,765,000
Extra Costs (acre)	0	0
Base & Surfacing (feet)	108,589	70,583,000
Ret. Wall	0	0
Culvert	1,613	806,000
Viaduct	0	0
Tunnel	0	0

Violations: S_Grade V_Curve

The user can either view all 50 alignments together (Compare mode), color coded by total cost (Figure 5), or each alignment can be viewed individually (Review mode) in plan and profile (Figure 6) with earthworks and cut-and-fill limits displayed. The Review option also includes a quantity and cost summary window (Alignment review summary, as shown above), and a dynamic cross section viewer and mass haul diagram (showing the balance between cut and fill along the alignment) that make it easy to locate large cut or fill areas along the alignments (Figure 6).

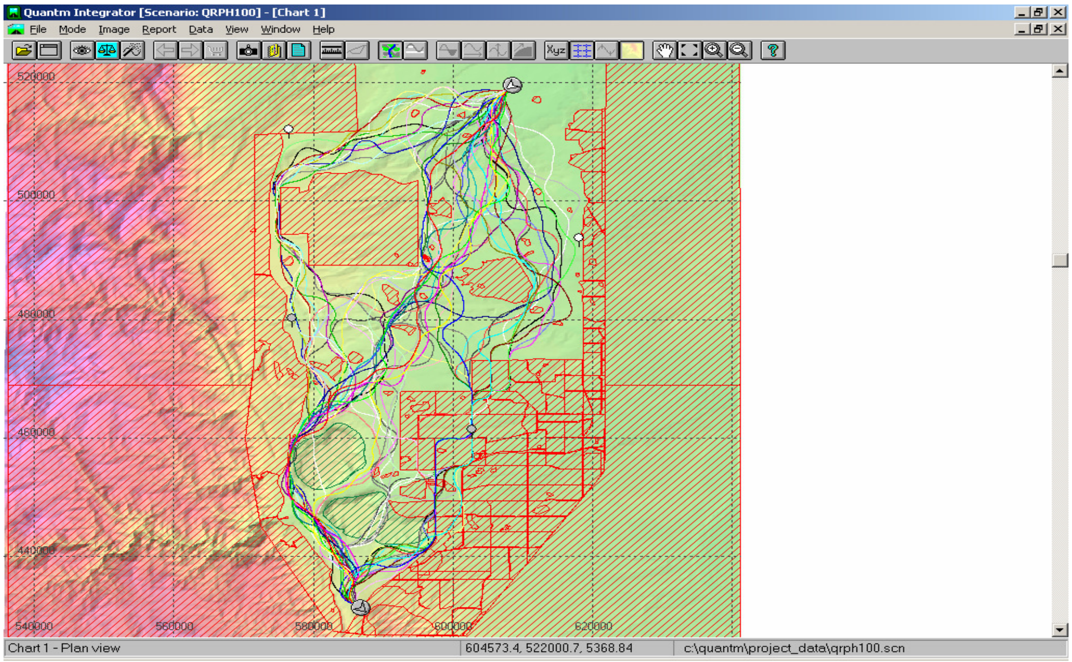


Figure 5: Example of 50 Alignments in Plan View

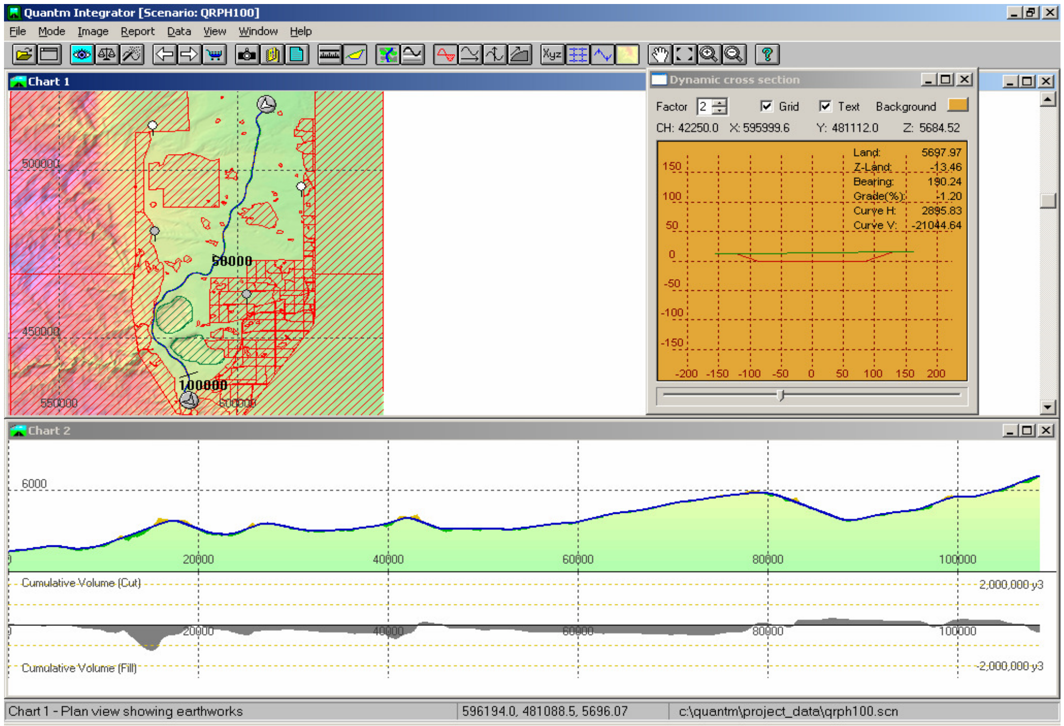


Figure 6:
Example of Single Alignment Shown with Profile (Blue Line Represents Alignment) and Mass Haul Diagram (Grey Areas Represent Volumes of Cut and Fill) and Cross-Section (Red Line Represents Roadway in Cut Cross-Section)

2.3 Organization of the Final Report Document

This document comprises the final deliverable for the project, pulling together the results of the project tasks described in Section 2.1. Section 3.0 describes the training that is provided to Quantm users and its importance to a Quantm project. Section 4.0 describes the evaluation of Quantm using the pre-NEPA data set, and Section 5.0 describes the evaluation of Quantm using the NEPA data set. Section 6.0 reviews previous user experiences and provides a cost/benefit analysis. Finally, Section 7.0 describes the overall conclusions and recommendations of the study. Appendices are provided at the end.

3.0 QUANTM TRAINING

The purpose of this task was to attend and evaluate the training class that is provided by Quantm as a part of their software license. This section discusses the training class format, curriculum, and value.

3.1 Training Scope

For Task 3 of the Quantm research project, Quantm provided training in the use of their software at the Carter & Burgess Denver office from Tuesday, March 15 through Friday, March 18th, 2005. Adrien Patane from Quantm instructed the class, with assistance from Hector Tamez and Len Bettess. Class attendees included Brann Greager, Jim Krogman, and Brian Werle from Carter & Burgess, and Shannon Philippus from DTD.

3.2 Training Curriculum

Quantm software training consists of four full days of classroom instruction. Typically, Quantm will provide the training from mid-day Monday to mid-day Friday, but the option is available for a four-day class from Tuesday morning until Friday afternoon. For this project, the four-day option was chosen.

The curriculum for the training included two days of instruction in use of the system (with a sample/training data set) and two days of working with the software using project data. A summary of the schedule is provided below.

DAY 1

- Introduction to Quantm / Background / Class Overview
- Introduction to Quantm Data Files
- Basic Cost Data Input and Scenario Notes
- Submission to Quantm Pathfinder (topographic constraints only)
- Methodology of Reviewing and Comparing Alignments
- Basic Constraint Data Input
- Submission to Quantm Pathfinder And Summarize Day's Work (Integrator Check List)

DAY 2

- Receipt and Review of Day 1 Quantm Pathfinder Submissions (Revise & Resubmit)
- Introduction to Seeded Refinements and Realignments
- Receipt and Review of Morning Quantm Pathfinder Submissions
- Explanation of Reports Pull Down Menu
- Explanation of View Pull Down Menu Options
- Summarize Days Work (Integrator Check List)

DAY 3

- Quantm Operations, System Help, Faqs, Help Desk, User's Manual
- Quick Review of Training

- Begin Client Project Data (Project Objectives, Project Setup, Data Input)
- Submission to Quantm Pathfinder (Topographic Constraints Only)
- Receipt and Review of Morning Quantm Pathfinder Submissions
- Project Constraint Data Input
- Submission to Quantm Pathfinder
- Review of Menu Structure and Icons and Integrator Features
- Refinement Using Seed Alignment
- Submission to Quantm Pathfinder
- Summarize Day's Work (Integrator Check List)

DAY 4

- Receipt and Review of Day 3 Quantm Pathfinder Submissions
- Assist Project Team in Project Data On-Site
- Revise Constraints
- Submit Revised Runs to Quantm Pathfinder
- Receipt and Review of Morning Quantm Pathfinder Submissions
- Assist Project Team in Project Data On-Site
- Summary / Conclusion / Course Evaluation

3.3 Training Results and Recommendations

Overall, the Quantm training was effective and well executed. Class participants gave the class high marks in all areas of evaluation and came away with confidence in the ability to work with the Quantm system. Because of the high level of experience of the Quantm trainers, they were able to answer a broad range of questions immediately and thoroughly. Also, the 24-hour support from Australia during the training allowed for rapid turnaround of project scenarios. This rapid turnaround was a big help in quickly understanding how Quantm responds to various inputs and changes to the project data.

The four-day training class is a critical step in the use of the Quantm system on an alignment study. Based on our experience with the training class, we have the following training recommendations for successful application of Quantm on future studies:

1. The personnel receiving Quantm training should be key personnel for the project. We feel that the most successful use of Quantm would involve project task managers using the software, rather than solely GIS or computer-oriented professionals.

2. Planners and engineers should be involved in the process. Because Quantm's strength is in its ability to consider engineering and environmental parameters concurrently, the best makeup of a Quantm training class would include at least one planner, one engineer, and one professional with GIS expertise.

3. Attendees should take advantage of the high level of support and expertise immediately available during training. We recommend that attendees send in as many scenarios as possible during the training session in order to take advantage of trainer availability and

quick turnaround. Sensitivity analyses might also be accomplished during the training session so that the experts are available to help understand the results.

4. Project decision-makers (managers) need to understand the Quantm process. Because Quantm is best used as an integral part of an alignment study, project managers should have a strong understanding of its uses and limitations. We recommend that when Quantm is used, project managers either attend the Quantm training or have class attendees prepare an in-depth presentation that summarizes the training class.

4.0 PRE-NEPA ANALYSIS

The purpose of the Pre-NEPA analysis was to investigate the usefulness of Quantm when the data inputs are only those available prior to the beginning of a NEPA transportation planning study. For the Quantm Pre-NEPA evaluation, the study team applied the knowledge gained in the Quantm training class and the data available at the beginning of the Case Study project to develop alignments for the project. For the purpose of this evaluation, the team sought to develop alignments that met the constraints corresponding to the "universe of alternatives" and to the Level 1 alternatives from the Case Study EIS. The following sections describe the study methodology.

4.1 Study Methodology

To create the range of Pre-NEPA Scenarios, the study team adjusted the various data files described in Section 2.2.1 according to a variety of strategies. In general, the team focused on adjusting engineering parameters based on facility types, and adjusting the nature of the special zones based on the category of GIS data entered. Scenarios were compiled from the adjusted data files, and then the scenarios were submitted to Quantm as unseeded runs. For the most part, different scenarios were based on varying the definitions of special zones to describe either avoidance areas or areas that resulted in additional costs when impacted.

In order to determine the usefulness of alignments produced, the study team looked at whether alignments: 1) met constraints set forth in the scenario; 2) could be used in the NEPA process; 3) stayed within the project area; and 4) followed standard roadway design practice. Because of the large number of scenarios runs (about 120) and the large number of alignments generated (about 5,000) for the Pre-NEPA portion of the study, this report does not evaluate the scenarios or alignments on a case-by-case basis. Rather, Section 4.2 provides an illustrated cross-section of examples of the types of scenarios that were investigated, as well as the alignments that resulted from their runs. For the purpose of consistency, the example scenarios are focused on the West-side case as described in Section 2.2.1.3. Section 4.3 outlines additional studies that were performed as part of the Pre-NEPA analysis, and the overall results of the Pre-NEPA analysis are summarized in Section 4.4.

4.2 Results: Scenario Examples

4.2.1 *Scenario Example A: Additional Cost Zones*

For this scenario, several special zones were designated as avoidance areas, while most were assigned additional costs when crossed by an alignment. The general land use avoidance areas included mountain backdrops, Rocky Flats, and reservoirs. Additional cost zones included $500,000 per acre for residential land, $1,000,000 per acre for commercial land, $20,000 per acre for floodplains, and $100,000 per acre for open space. Costs were approximated for comparison purposes only and do not reflect actual land costs, which may vary significantly. Figure 7 depicts the Quantm scenario and the resulting alignments (shown with and without special zones). Figure 8 illustrates the resulting alignments overlaid with the routes created for investigation at the outset of the Case Study project (the "universe of alternatives").

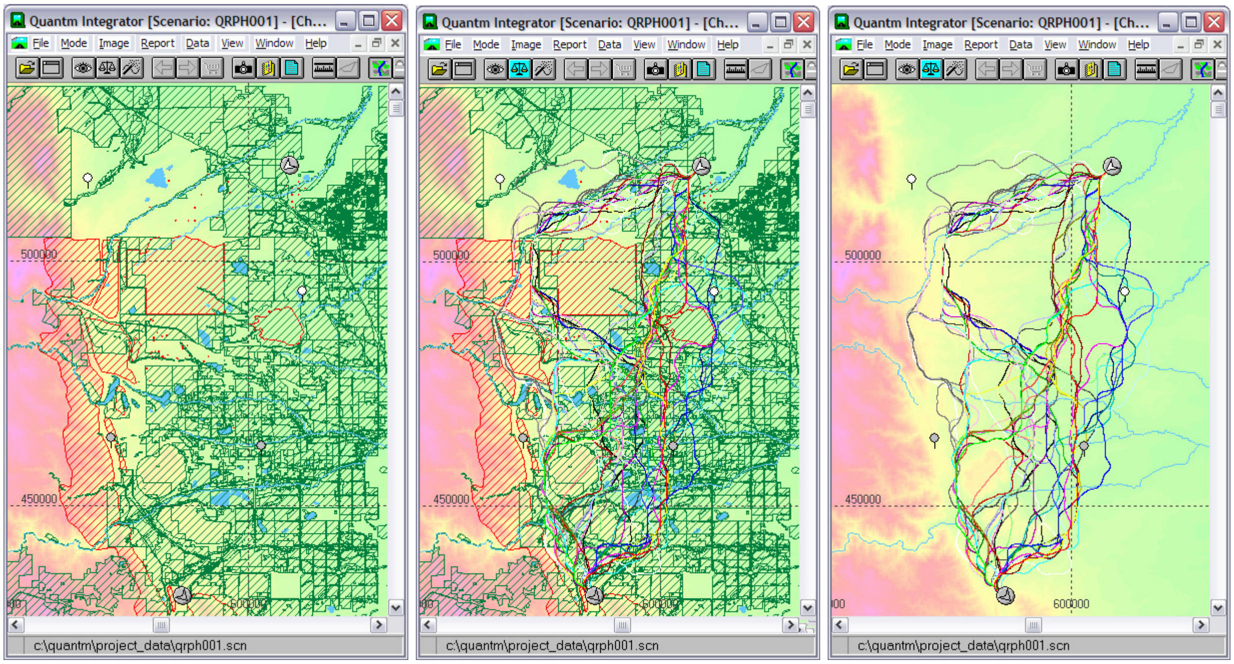


Figure 7:
Screen Shots of Scenario Example A with Resulting Alignments (Quantm alignments are isolated on the right)

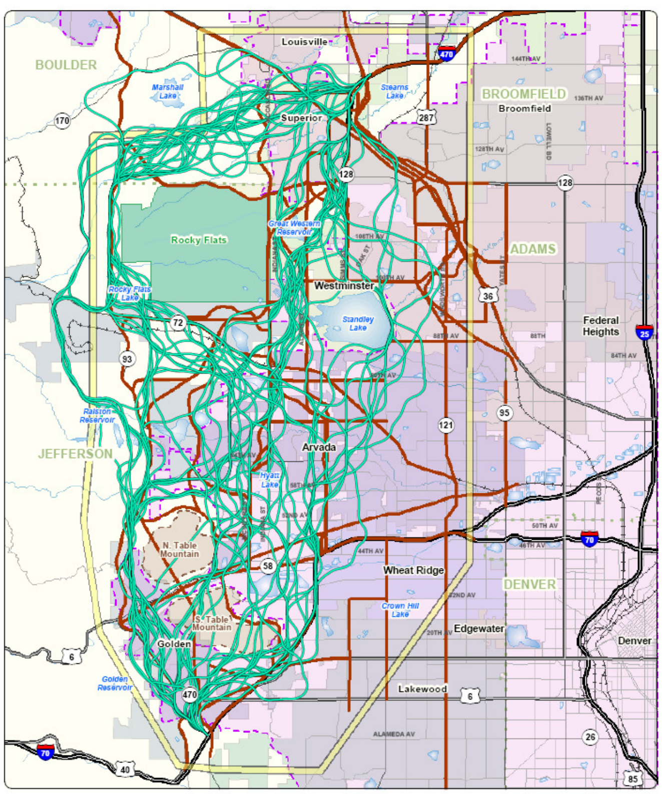


Figure 8:
Scenario Example A Alignments (green) Compared to Case Study Alternatives (red)

4.2.2 Scenario Example B: Avoidance of Residential and Commercial Areas

For this scenario, residential and commercial zones were designated as avoidance areas, in addition to the baseline avoidance areas of mountain backdrops, Rocky Flats, and water bodies. This example represents the most highly constrained scenario evaluated during the Pre-NEPA study. Figure 9 depicts the Quantm scenario and the resulting alignments, and Figure 10 illustrates the results overlaid with the Case Study alignments.

Residential Avoidance Areas:

- Golden
- Arvada
- Louisville
- Broomfield
- Unincorporated Jefferson County
- Unincorporated Boulder County

Commercial Avoidance Areas:

- Flat Irons Mall
- Interlocken Business Park
- Coors Brewery
- Downtown Golden
- Jefferson County Airport
- Colorado School of Mines
- Jefferson County Municipal Center
- Colorado Mills
- Denver West Business Park

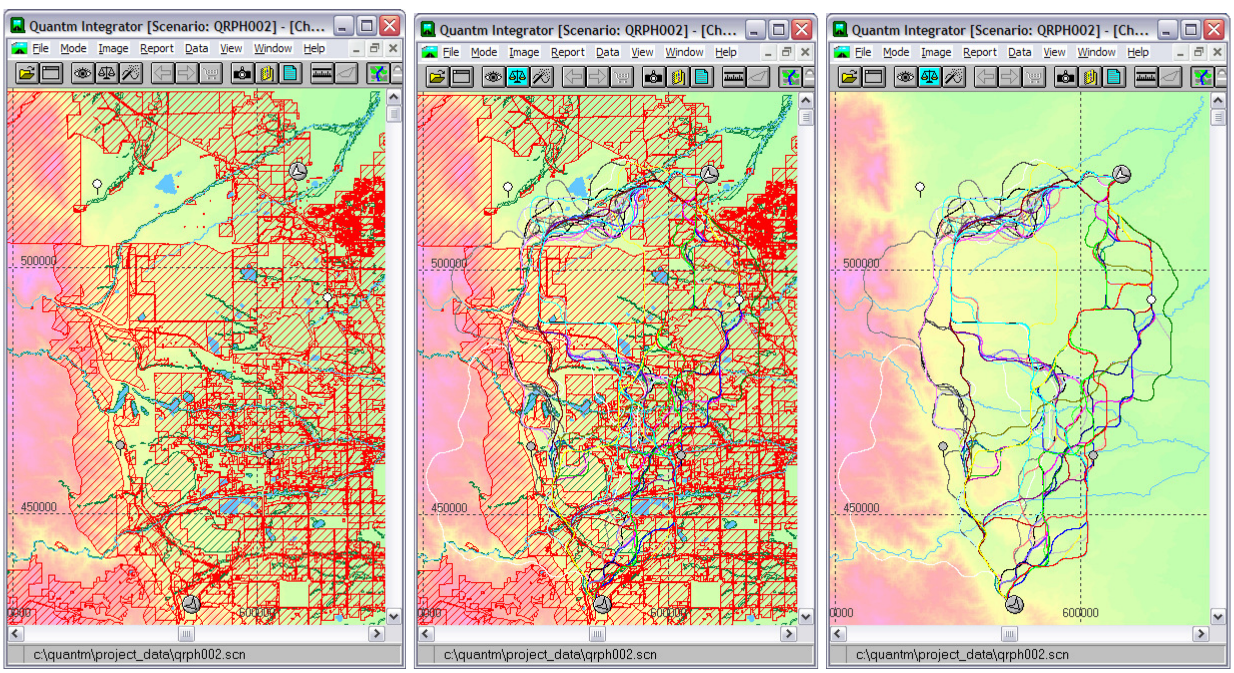


Figure 9:
Screen Shots of Scenario Example B with Resulting Alignments (alignments on right)

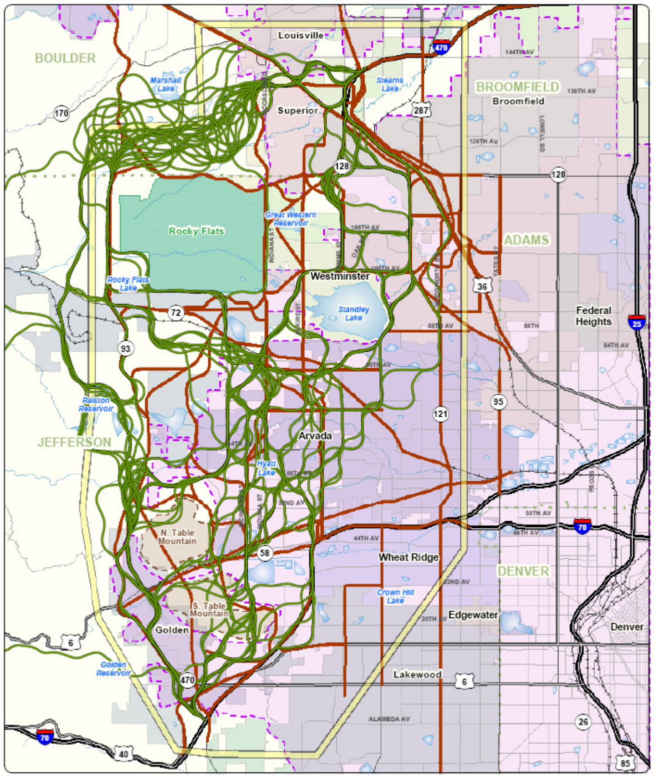


Figure 10:
Scenario Example B Alignments (green) Compared to Case Study Alternatives (red)

4.2.3 *Scenario Example C: Avoidance of Public Parks And Water Bodies*

In addition to the baseline avoidance areas of mountain backdrops, Rocky Flats, and water bodies, this scenario evaluation designated public parks and reservoirs as avoidance areas and residential and commercial zones as additional cost areas ($500,000 per acre for residential land and $1,000,000 per acre for commercial land). Figure 11 depicts the Quantm scenario and the resulting alignments, and Figure 12 illustrates the results overlaid with the Case Study alignments.

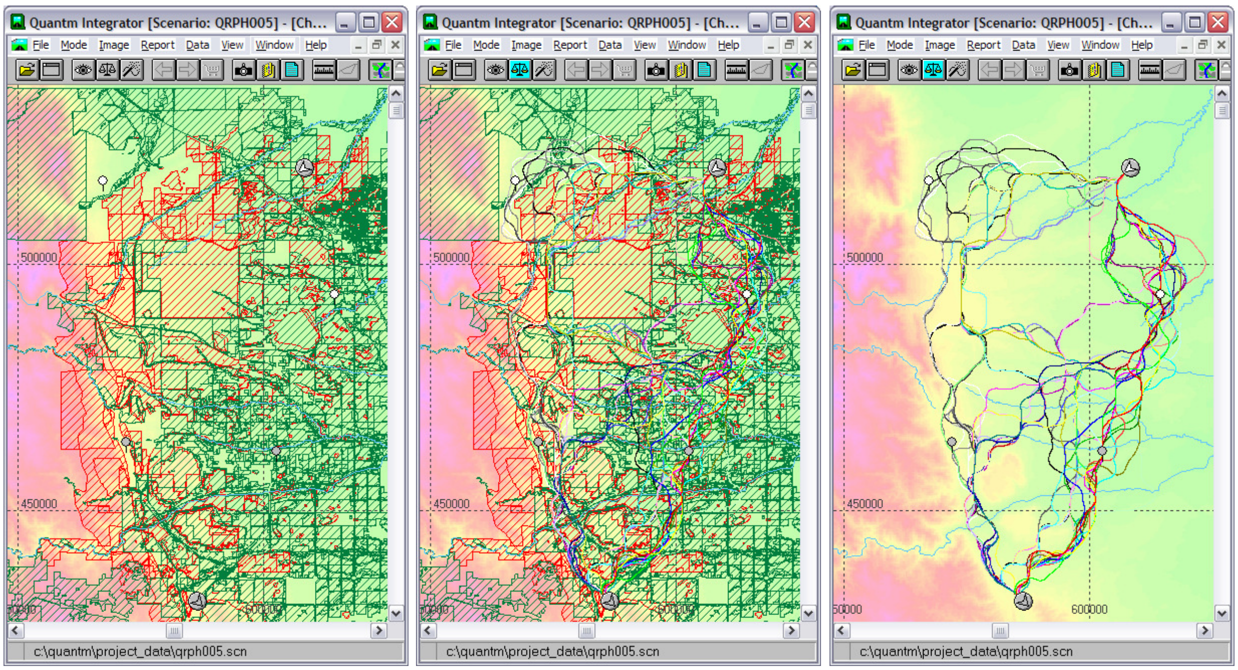


Figure 11:
Screen Shots of Scenario Example C with Resulting Alignments on the right

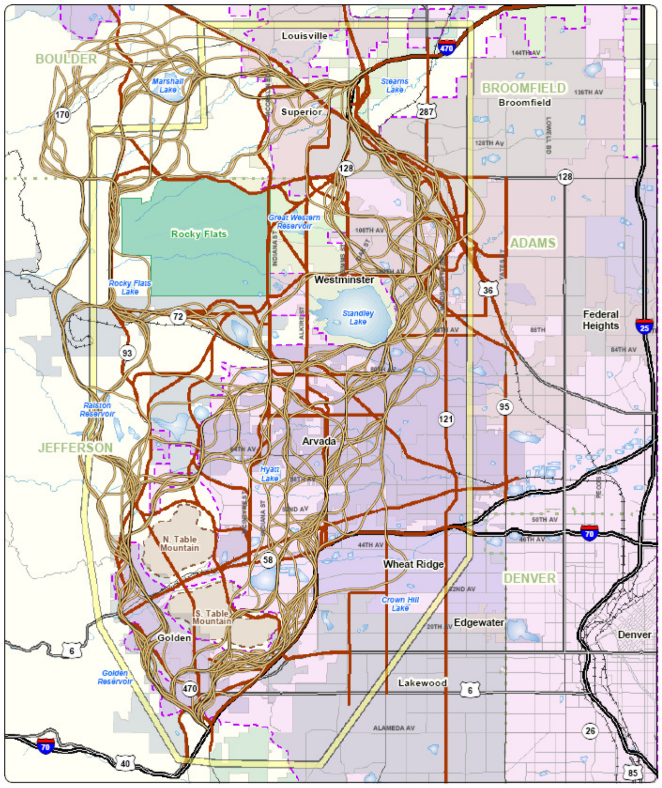


Figure 12:
Scenario Example C Alignments (brown) Compared to Case Study Alternatives (red)

4.2.4 *Scenario Example D: Level 1 Screening*

For comparison to the Case Study Level 1 screening process, the evaluation team constructed GIS data layers to reproduce the Case Study Level 1 regionally-sensitive resources for use in the Quantm application. Figure 10 depicts the pre-NEPA scenario used for the Quantm evaluation, along with the resulting alignments. For this scenario, the alignments all appear to meet the Case Study Level 1 constraints (Figure 13). In terms of general routes, the alignments correspond to the range of alternatives from the Case Study EIS. However, the alignments follow existing roadways closely only where they are forced to by avoidance areas surrounding roadway corridors (in the Southeast portion of the study area).

Regionally-Sensitive Resources Avoided

- ✓ Rocky Flats
- ✓ Reservoirs
- ✓ East of Wadsworth
- ✓ Tops of South & North Table Mountains
- ✓ West of 93 Foothills
- ✓ Residential between Wadsworth and Ward Road
- ✓ Residential between Ward Road and McIntyre

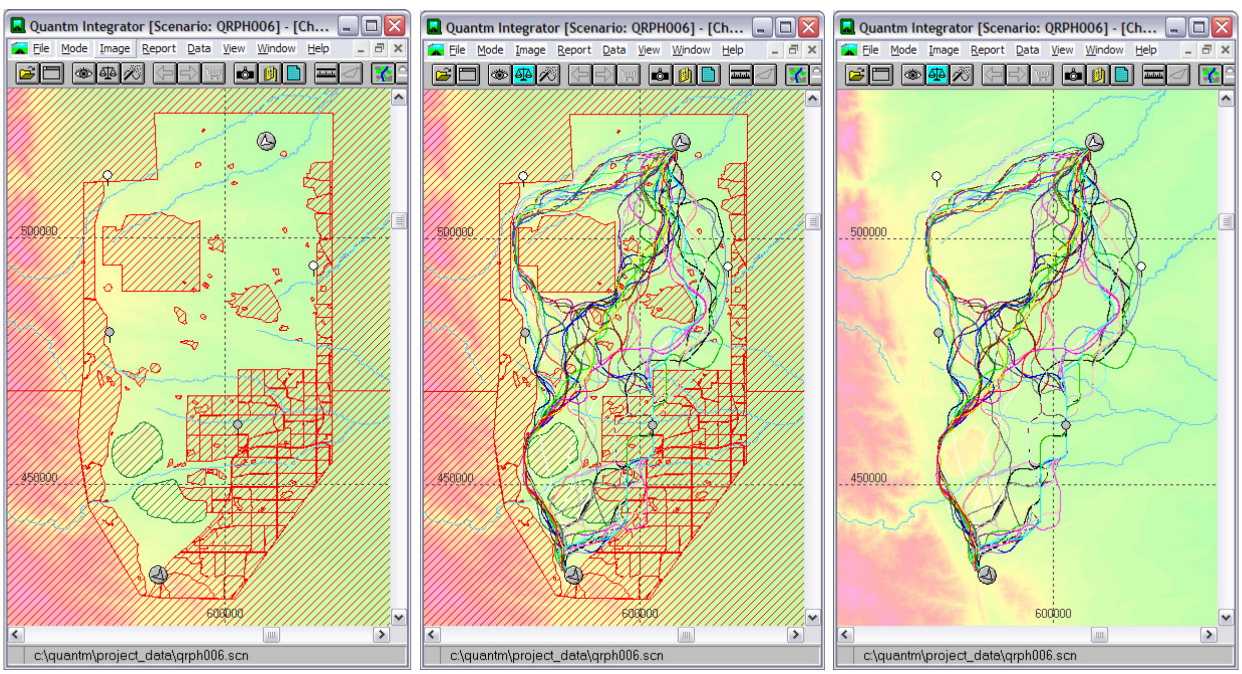


Figure 13:
Screen Shots of Scenario Example D with Resulting Alignments

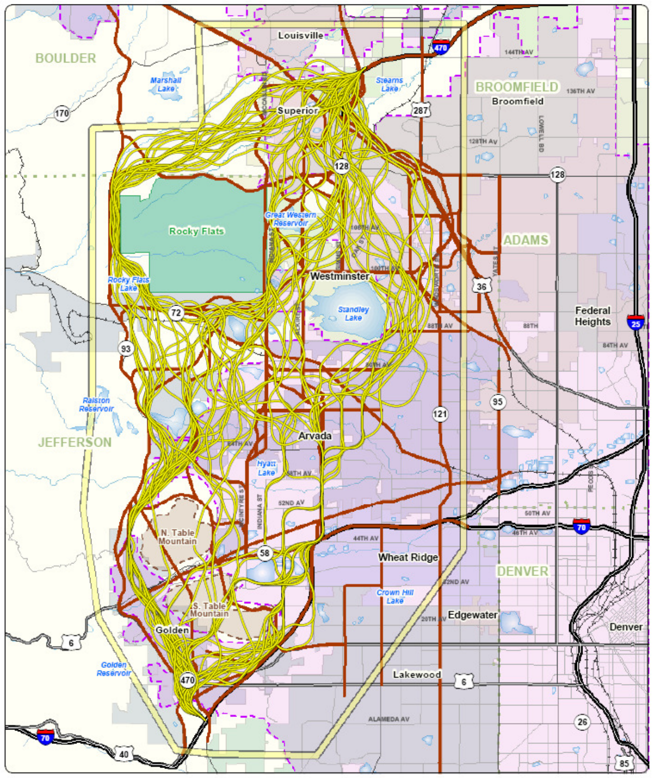


Figure 14:
Scenario Example D Alignments (yellow) Compared to Case Study Alternatives (red)

4.2.5 *Scenario Example E: Localized Unseeded Run*

In order to simulate an alignment where only a portion is not fixed on an existing roadway, the study team created this scenario to investigate possible alignments connecting the north end of the project with Hwy 93 at the Northwest corner of Rocky Flats. This scenario used the same constraints and avoidance areas at Scenario D (Level 1 Screening constraints), but used a different end point to focus the unseeded run. Figure 15 shows the scenario with its special zones and resulting alignments, and Figure 16 shows the results of the localized run overlaid with the Case Study alternatives.

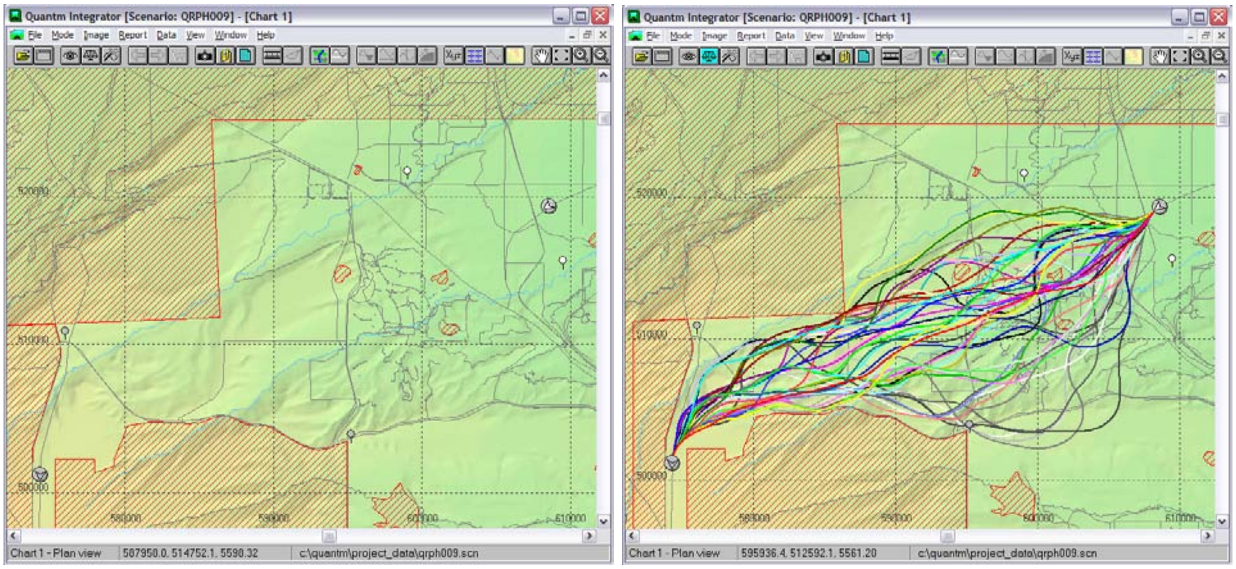


Figure 15:
Screen Shots of Scenario Example E with Resulting Alignments

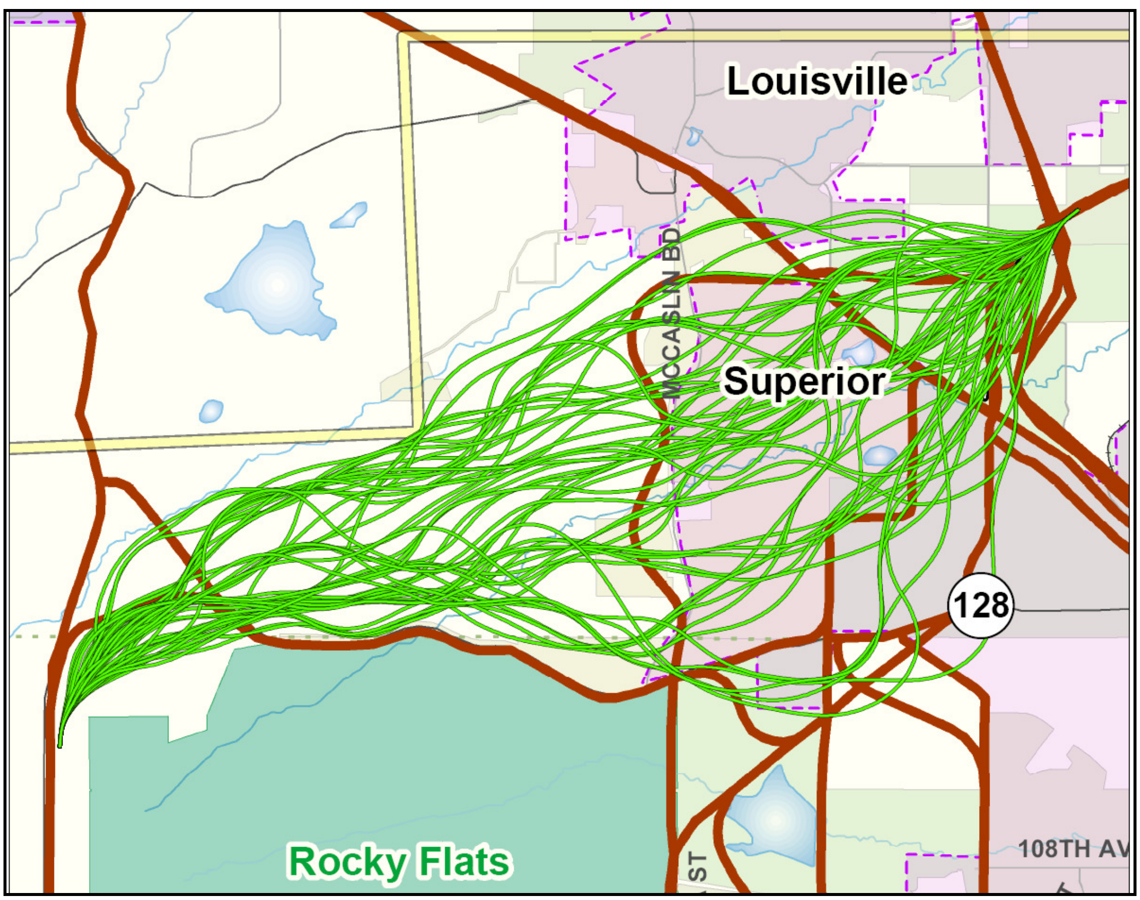


Figure 16:
Scenario Example E Alignments (green) Compared to Case Study Alternatives (red)

4.3 Additional Studies

This section provides a summary of other studies performed by the evaluation team including analyses of sensitivity to varying input parameters and an investigation of the refining of individual alignments.

4.3.1 *Sensitivity to Varying Input Parameters*

Sensitivity analyses involve holding most parameters of a study constant while varying a single parameter. For the Pre-NEPA sensitivity analyses, the runs were based on a freeway template in the west corridor and an arterial template in the east corridor.

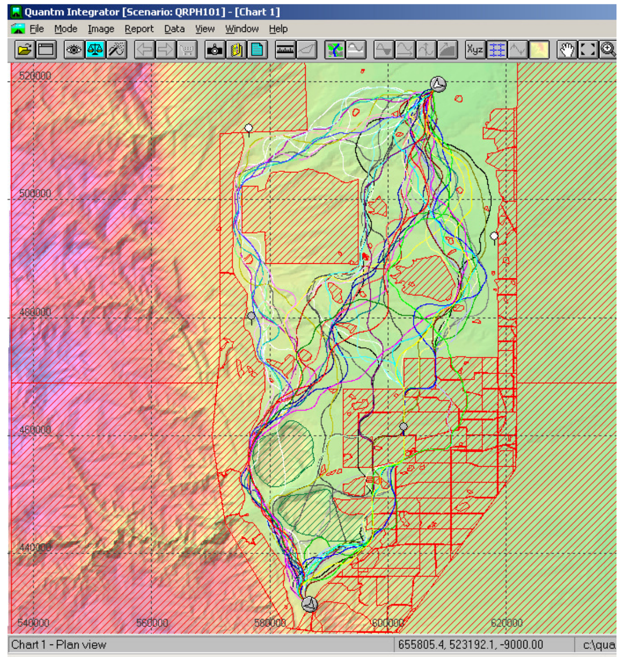


Figure 17: Stiffness Equals 0.0

Stiffness. Quantm alignment generation is based on curved roadway sections, with variations in direction and radius of curves. Stiffness represents the total number of curves along a given alignment, with a stiffness of 0 allowing a maximum number of curves and a stiffness of 1 allowing the minimum number of curves. To understand how the stiffness factor affects the alignment location the following values were used and new runs were submitted: 0, 0.1, 0.25, 0.5, 0.75, 0.9 and 1.0. Using a value of 0 for both horizontal and vertical resulted in a very 'curvy' plan layout and profile (Figure 17). The resulting earthwork quantities were minimized; hence the cut/fill cost was low. No significant changes were observed with the values of 0.1, 0.25, 0.5 or 0.75. Values of 0.9 and 1.0 increased the earthwork significantly (Figure 18). For example, the earthwork mass haul value for the freeway section in the west corridor increased over 100% from a stiffness of 0 to a stiffness of 0.9.

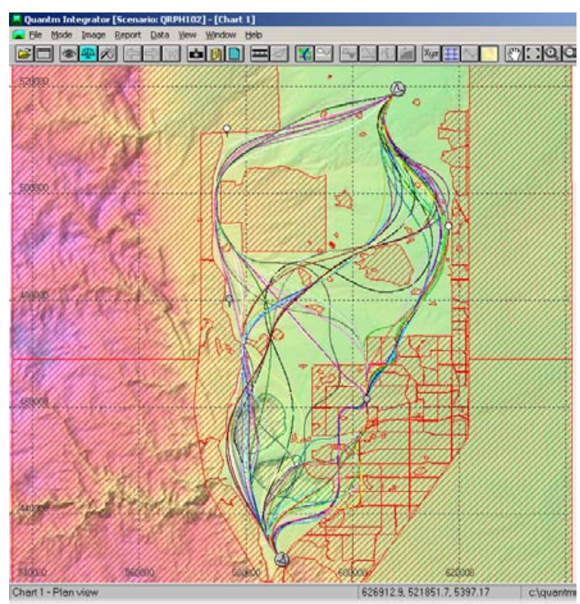


Figure 18: Stiffness Equals 1.0

We concluded that a vertical stiffness factor of 0.5 would give a better profile in relation to the existing ground and a horizontal factor between 0.5 and 1.0 would allow for some curviness, but also a more direct route.

Horizontal Radius. The horizontal radius is the radius of the arc of a roadway when viewed from above. In Quantm, the user identifies the minimum horizontal radius allowed for the roadway. Increasing the minimum horizontal radius on the arterial section from 1200 feet to 2000 feet increased the costs from 10-25% (Figures 19 and 20). The minimum horizontal radius corresponds to the superelevation rate of 6% that is used for the Case Study design. During actual design a more reasonable method might be to generally use greater than the minimum values. The 2000-foot radius represents this approach.

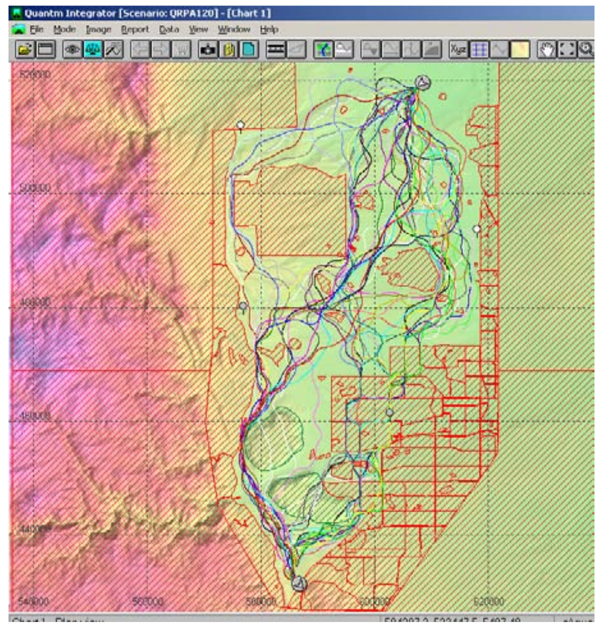


Figure 19:
1200-foot Horizontal Radius

K Value. The K value is a coefficient used to determine what length of vertical curve will provide safe stopping sight distance. Increasing the length of vertical curves by increasing the crest and sag K values did not show a significant increase in costs. The minimum K values for the design speed were compared to larger values more in line with actual design.

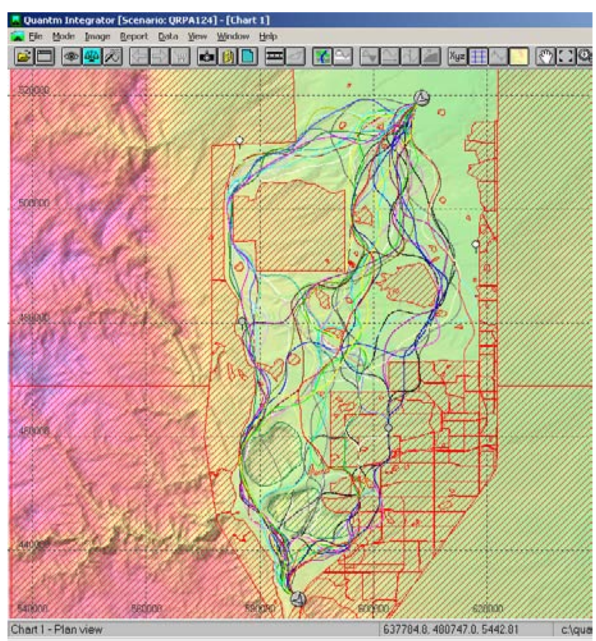


Figure 20:
2000-foot Horizontal Radius

4.3.2 *Refining Alignments*

Of the fifty alignments returned from the Quantm Pathfinder system, individual or seed alignments can be selected for refinement. A "total refinement" optimizes the seed alignment both horizontally and vertically with new routes close to the seed alignment. A "total intensive refinement" produces new routes very close to the seed alignment with minor horizontal and vertical adjustments and a vertical refinement will adjust the vertical only. Each one of these refinements will create twenty new alignments.

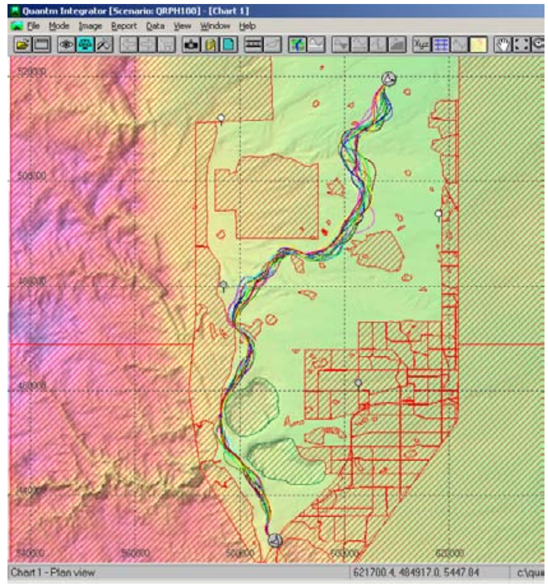


Figure 21:
Total Refinement—Highway Option West-Side Case

Using these refinements, an alignment from the west corridor highway template and the east corridor arterial template were chosen based on location (Figures 21 and 22). The selected highway alignment tended to run through less developed land in the study area. A total refinement was submitted for this alignment and twenty new alignments were developed. The new alignments varied within ½ mile on either side of the seeded alignment and the costs were evenly divided above and below the seeded alignment cost with a 40% difference from high to low. Of the fifty arterial alignments, the selected seed alignment followed a more direct north-south route. As with the highway total refinement, the arterial total refinement also created new alignments within ½ mile of the seed alignment. In this case all of the refined alignments were less expensive than the seed alignment and costs were within 15% from high to low.

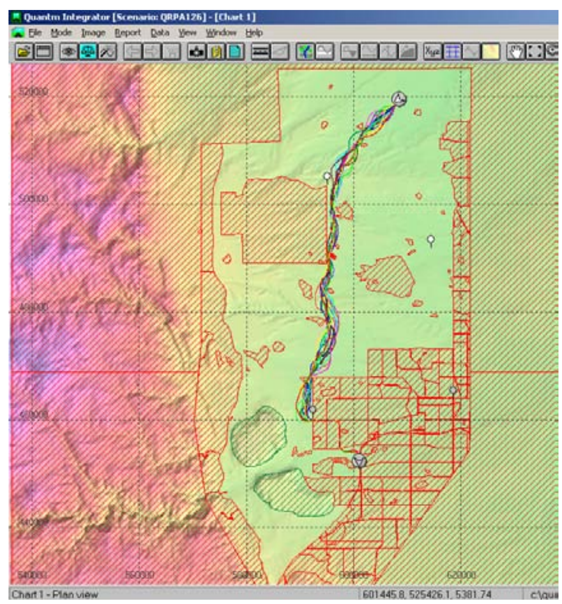


Figure 22:
Total Refinement—Arterial Option East-Side Case

A total intensive refinement was submitted for the same two seed alignments. In the west corridor highway template, the twenty new routes closely followed the seed alignment and the high cost was less than 30% above the low cost (Figure 23). The twenty new arterial alignments in the east corridor showed a difference in costs of less than 8% (Figure 24).

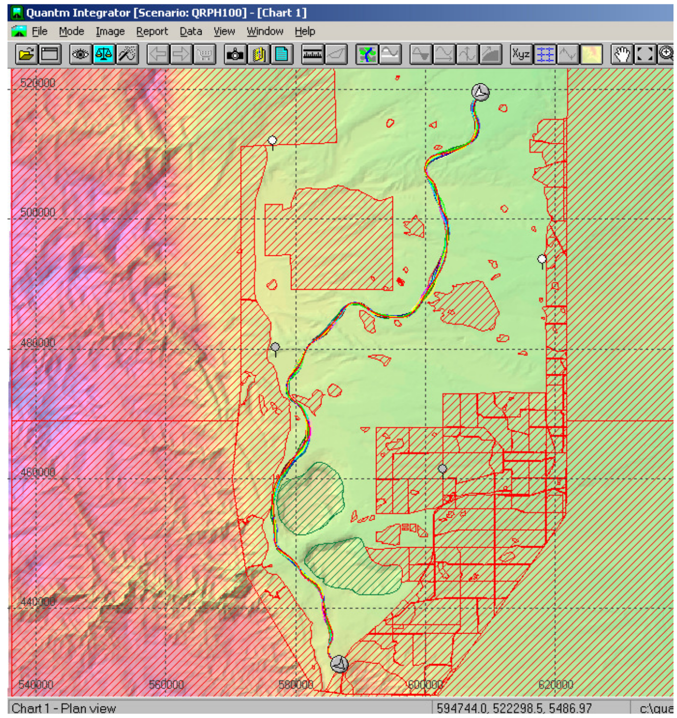


Figure 23:
Total Intensive Refinement – Highway Option West-Side Case

Using the vertical refinement feature to optimize the cut and fill quantities, the arterial seed alignment cost was reduced by 2.5% while the highway option showed a savings of 4.5%. The savings from this optimization apply not only to earthwork, but also to wall and culvert items due to the balancing of the profile.

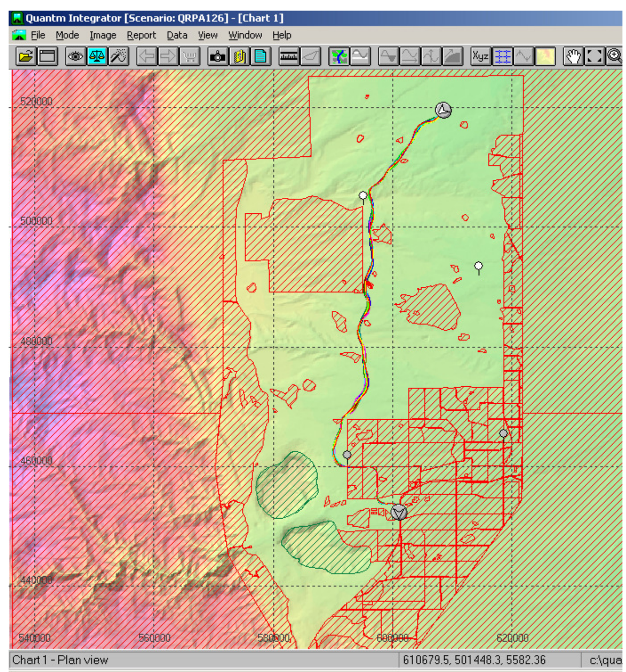


Figure 24:
Total Intensive Refinement—Arterial Option East-Side Case

Another option available to use with seed alignments is creating an alignment from selecting existing features, using an xyz data file, or a quick seed method of selecting points. A quick seed was created for the arterial template in the east corridor and was selected by picking points with the mouse that generally followed existing road alignments (Figure 25). Using the Quantm horizontal curvature option indicated violations with red colored bands. A total intensive refinement was submitted for the quick seed alignment in the same manner as a seeded optimization, and twenty new routes were produced that closely matched the quick seed and used the network criteria to better define the corridor (Figure 26). The horizontal curvature bands indicate alignments within the design parameters.

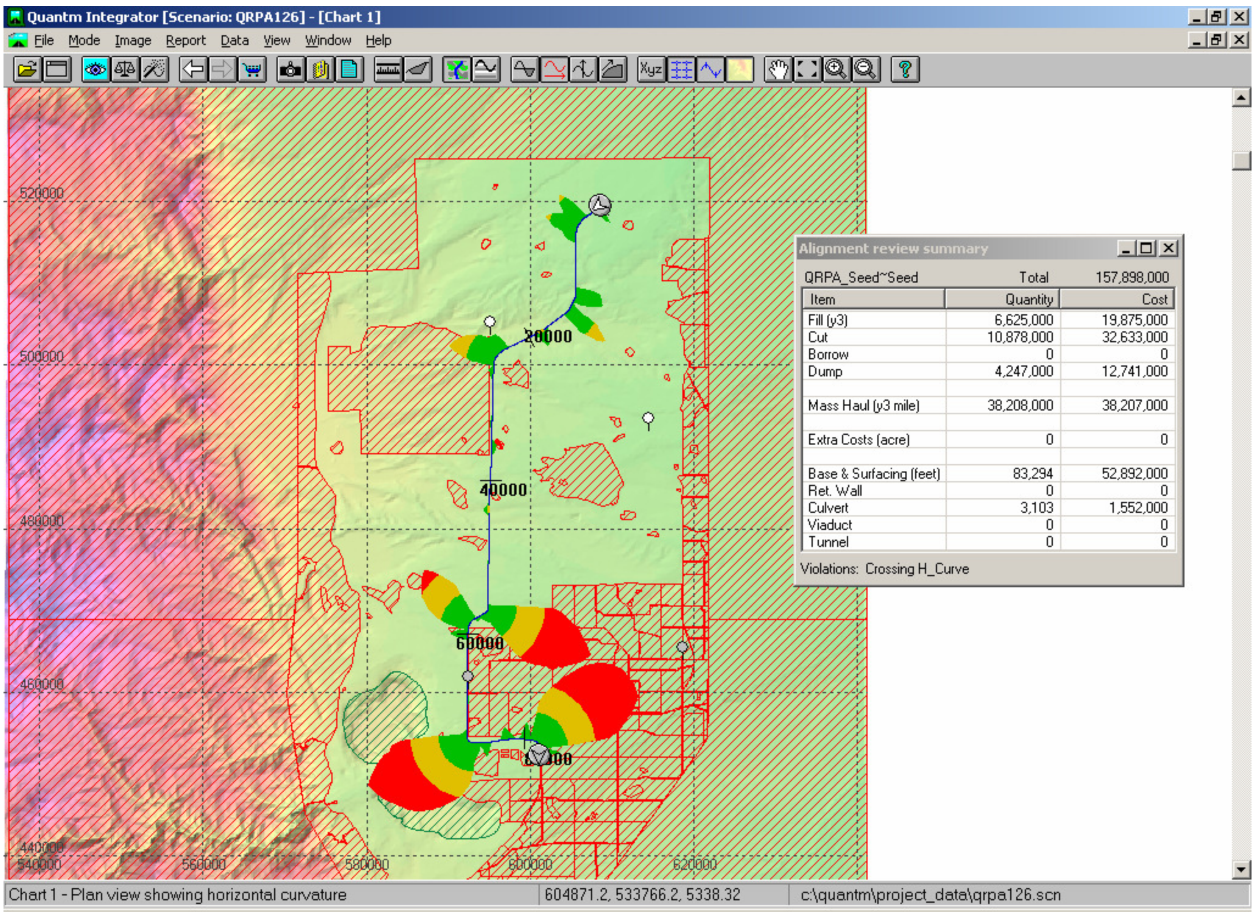


Figure 25:
Quick Seed Alignment – Arterial Option East Corridor (colored areas represent horizontal curvature, with violations of minimum radius shown in red)

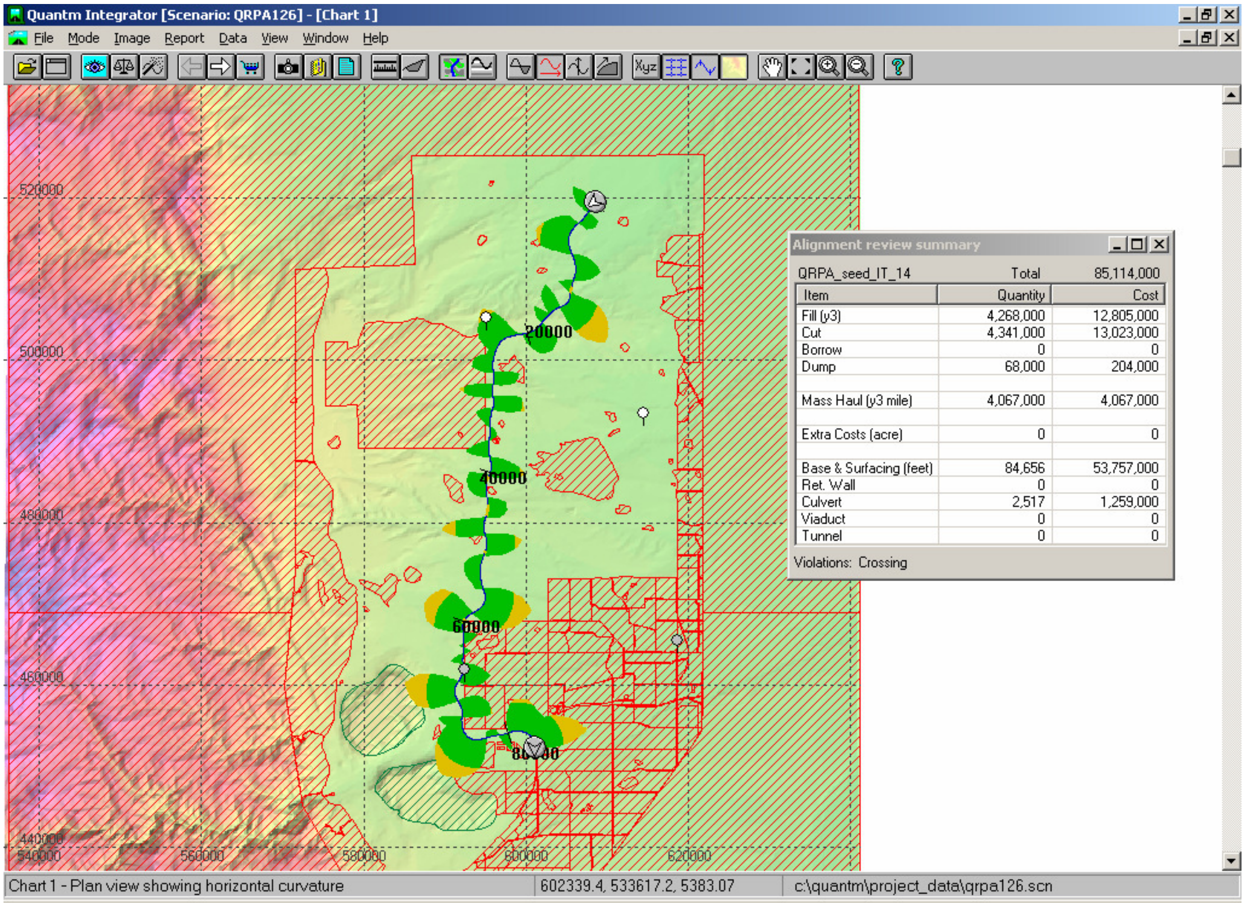


Figure 26:
Quick Seed Total Intensive Refinement – Arterial Option East-Side Case (colored areas represent horizontal curvature where green is twice the minimum curvature or greater, green and amber are between the minimum and twice the minimum, and a red fringe would represent a curve violation)

4.4 Pre-NEPA Findings/Observations

The following are the key observations of the study team at the completion of the Pre-NEPA analysis:

1. For the Pre-NEPA scenarios, the great majority of alignments generated appeared to satisfy the parameters represented by the scenario. When the parameters were violated, or when alignments were generated that were obviously implausible, the Quantm support staff would indicate the reason for the anomaly and suggest how the user inputs could be adjusted to correct it.

2. Most of the alignments produced were considered "useful" by the project team, with an exception where portions of the road would necessarily be straight. Quantm unseeded runs produce alignments that do not have straight portions (and often a large number of curves). On the other hand, standard design practice in urban areas can include significant stretches of straight roadway due both to property issues and to reduce road length and driver miles. Section 4.3.1 describes the stiffness factor, which can be used

to reduce the number of curves allowed along the roadway alignments generated by Quantm. However, for alignments with truly straight portions, users must manually delineate those straight portions.

3. For unseeded runs, alignments avoided special zones that were set up as ‘avoids’ almost completely. In cases where other constraints forced an alignment through an avoid zone, the alignment would skirt the edge of the avoid zone rather than passing through the center of it.

4. Additional cost zones did not appear to have a strong effect on the routing of alignments in unseeded runs. However, they did assist in the comparison of the relative cost of different alignments within a given scenario.

5. There is no direct way in Quantm to cause unseeded runs to favor existing roadways, other than by avoiding non-roadway areas. However, alignments along existing roadways can be digitized into the system for comparison with other alignments in a scenario. In general, however, Quantm generated a range of alignments that was comparable to those generated in the Case Study EIS.

6. Sensitivity analyses assisted the study team in understanding the importance of different parameters to the system, and the affect of varying those parameters on the resulting alignments.

7. Table 1 identifies the Pre-NEPA GIS data layers that were investigated for the study, including whether they were used in Quantm, the type of Quantm data created from the layer, the usefulness of the data in the Pre-NEPA evaluation, and notes on each layer.

Table 1: Pre-NEPA Data Layers Investigated for the Study

Layer	Used In Study	Type of Quantm Data	Usefulness	Notes
Base Map				
USGS DEM	YES	Terrain Model	HIGH	Critical to Quantm function; lower resolution suitable for early planning stage of EIS
Aerial Photograph	YES	Background Image	HIGH	Very helpful for reference & orientation, heads-up digitizing of manmade facilities
Functional Class Roads	YES	Linear Feature	HIGH	Important reference layer - buffered to "cut out" existing roadways
Highways	YES	Linear Feature	HIGH	Important reference layer - buffered to "cut out" existing roadways
Railroads	YES	Linear Feature	HIGH	Important reference layer
Rocky Flats Boundary	YES	Special Zone	HIGH	Example of an avoidance area that is known from project outset
Table Mesa Boundaries	YES	Special Zone	HIGH	Example of a special zone that is known from project outset
Counties	NO	Special Zone	MEDIUM	County Boundaries were not needed for Quantm analysis but serve as reference layers in GIS
City Boundaries	NO	Special Zone	MEDIUM	City Boundaries were not needed for Quantm analysis but serve as reference layers in GIS
Bridges	NO	Special Zone (buffered points)	LOW	At the planning stage, not needed for Quantm analysis

Bike Trails	NO	Linear Feature	LOW	Not needed for Quantm analysis, may be used as a reference layer
Geology				
Sand & Gravel	NO	Geology	MEDIUM	Probably not needed for early planning work, but could help in engineering phase
Hydrology				
Lakes and Reservoirs	YES	Special Zone	HIGH	Generally avoidance areas (otherwise bridge/viaduct crossing)
Streams and Rivers	YES	Linear Feature	HIGH	Important reference layer, can be used for linear features
Q3 Floodplain Data	YES	Special Zone	MEDIUM	Could be used to identify higher construction costs for flooding mitigation - probably not avoidance
Flora/Fauna				
T&E Species Habitat	NO	Special Zone	LOW	Preliminary data may be inaccurate enough to be misleading – best as NEPA data
Wetlands	NO	Special Zone	LOW	National wetlands inventory is generally inaccurate enough to be misleading – best as NEPA data
Land Use				
Visual Corridors	YES	Special Zone	MEDIUM	Could be used as avoidance areas
City/County Parcels	NO	Special Zone	LOW	Too much detail for planning portion of study
Parks and Rec Areas	YES	Special Zone	HIGH	Parks and Rec areas were used in Quantm analysis as either avoidance zones or extra cost zones
City and County Land Use Layers	NO	Special Zone	LOW	Land use codes were too inconsistent between different jurisdictions to be of use
City and County Zoning Layers	YES	Special Zone	MEDIUM	Zoning codes were inconsistent but were merged into one layer - difficult to simplify
OilGas				
COGCC Oil and Gas Facilities data set	YES	Special Zones (buffered points)	MEDIUM	Although small, these locations could be used as avoidance areas

5.0 NEPA ANALYSIS

The purpose of this section is to describe the results of applying Quantm to data that was collected or developed as part of the NEPA study. The results were then used to evaluate the usefulness of Quantm during NEPA projects, and to compare the results of using Pre-NEPA data in Quantm to those achieved in using NEPA data.

5.1 Study Methodology

For the Task 5 Quantm evaluation, the evaluation team applied the knowledge gained in the Quantm training class, from the pre-NEPA evaluation (Task 4), and from more detailed environmental GIS data available from the Case Study project to develop and test Quantm NEPA alignments. The evaluation team ran a wide variety of Quantm analyses with the goal of testing alignment outputs that represented the range of alignments typically generated during the NEPA stages of a project.

Sections 5.2 through 5.5 provide a summary of the NEPA scenario development, results from the baseline NEPA scenarios, scenario testing, and the hypothetical NEPA scenarios for the East-Side and West-Side case studies (see Section 2.2.1.3). Section 5.6 outlines engineering studies that were performed using the NEPA data, and Section 5.7 provides the findings and observations related to the NEPA evaluation.

5.2 Quantm NEPA Scenario Development and Evaluation

NEPA scenarios were developed for the East-Side and West-Side case studies by building on the pre-NEPA scenarios considered in Task 4. The Task 4 analysis included basic environmental constraints corresponding to the "universe of alignments" and to the Level 1 screening of alignments for the Case Study project. These Level 1 avoidance criteria form the basis for all alignments developed throughout the pre-NEPA and NEPA process (i.e., they remain constant throughout). For the Task 5 NEPA analysis, Level 1 criteria were augmented with more detailed environmental spatial data (i.e., GIS data layers) including additional residential and commercial areas, surface and underground mines, landfills, biological resources, wetlands, hazardous materials sites, and parks and open space.

3-Step Quantm NEPA Evaluation Process

1. Create and analyze baseline scenario
2. Incrementally test and compare various NEPA scenarios
3. Analyze hypothetical NEPA combination scenario

To facilitate the analysis, a baseline NEPA scenario was developed from which to test the effects of NEPA data layers (special zones) on Quantm alignment development. NEPA scenarios were created for testing by incrementally changing the designation of each NEPA special zone from ignore to avoid to extra cost, one layer at a time, and sending them in to Quantm as unseeded runs. This methodology allowed the evaluation team to identify the overall impact of individual

NEPA data layers on alignment cost, length, volume of cut and fill, and extra costs. For example, wetlands were ignored in the baseline NEPA scenario. During the NEPA scenario testing, wetlands were changed to an avoidance area and the scenario submitted to Quantm for processing as an unseeded run, and another scenario was created that considered wetlands as an extra cost. The results of both scenarios were compared to each other and the baseline to determine the overall effect on alignment results. These results in turn were compared with changes from the other NEPA data layers to determine which layers had the greatest impact on Quantm alignments. The results of this analysis are summarized in Section 5.5.

Once the individual scenario testing was complete, the evaluation team created a hypothetical NEPA combination scenario that utilized the most probable NEPA constraint (ignore, avoid, or extra cost) for each data layer. For this analysis, one scenario was created that included wetlands, residential, commercial, hazardous materials sites as an extra cost and sensitive biological resources, open space, and landfills as an avoid. The hypothetical NEPA scenario also included the Level 1 constraints that were assumed throughout the NEPA analysis. Testing of this scenario included identifying specific alignments that had the least cost, length, cut and fill volumes, and extra costs as measured by impacted acres of extra cost features.

Special zones considered in the NEPA analysis were organized from GIS data files compiled by the Case Study project. These data files were originally developed by a large team of environmental scientists, biologists, and planners to support the transportation alignments development process. NEPA special zones for each of the three steps considered in this Quantm analysis are listed in Table 2. Land uses for the L1-Residential and L1-Commercial special zones in Table 2 are summarized in the side bars.

L1 - Commercial Areas:

- Flat Irons Mall
- Interlocken Business Park
- Coors Brewery
- Downtown Golden
- Jefferson County Airport
- Colorado School of Mines
- Jefferson County Municipal Center
- Colorado Mills
- Denver West Business Park

L1 – Residential Areas:

- Golden
- Arvada
- Louisville
- Broomfield
- Unincorporated Jefferson County
- Unincorporated Boulder County

Table 2: Quantm Special Zone Scenarios

Special Zone	Baseline *(Step 1)*	Scenario Testing *(Step 2)*	Combination Scenario *(Step 3)*
Rocky Flats Boundary	Avoid	Held Constant	Avoid
Table Mesa Boundaries	Extra Cost – Tunnel	Held Constant	Extra Cost – Tunnel
Green Mountain Boundary	Avoid	Held Constant	Avoid
Lakes and Reservoirs	Avoid	Held Constant	Avoid
Streams and Rivers	Ignore	Held Constant	Ignore
Q3 Floodplain Data	Ignore	Held Constant	Ignore
Prebles Jumping Mouse Habitat	Ignore	Avoid, Extra Cost	Avoid
Prairie Dog Habitat	Ignore	Avoid, Extra Cost	Avoid
Endangered Orchid Habitat	Ignore	Avoid, Extra Cost	Avoid
Eagle's Nests	Avoid	Held Constant	Avoid
Wetlands	Ignore	Avoid, Extra Cost	Extra Cost
Visual Corridors	Avoid	Held Constant	Avoid
Prime Farmlands	Avoid	Held Constant	Avoid
Parks and Recreation Areas	Avoid	Held Constant	Avoid
L1 – Residential	Ignore	Avoid, Extra Cost	Extra Cost
L1 - Commercial	Ignore	Avoid, Extra Cost	Extra Cost
Historic Properties	Avoid	Held Constant	Avoid
Section 4(f) Properties	Avoid	Held Constant	Avoid
COGCC Oil and Gas Facilities	Avoid	Held Constant	Avoid
Surface Mines	Ignore	Avoid, Extra Cost	Extra Cost
Hazardous Materials Sites	Avoid	Ignore, Extra Cost	Extra Cost
Landfills	Ignore	Avoid, Extra Cost	Extra Cost
Underground Coal Mines	Ignore	Held Constant	Ignore

Extra costs for specific special zones were approximated for comparison purposes only. Costs used in the Quantm NEPA study were similar to those used in Task 4 and are shown in Table 3.

Table 3: Extra Costs Used for the NEPA Evaluation

Special Zone	Extra Cost ($/acre)
Residential	$500,000
Commercial	$1,000,000
Wetlands	$100,000
Orchid Habitat	$100,000
Prairie Dog Habitat	$100,000
Prebles Jumping Mouse Habitat	$100,000
Hazardous Materials Sites	$5,000,000
Landfills	$10,000,000
Surface Mines	$1,000,000

From each scenario run, Quantm Pathfinder returned sets of 50 alignments, which the team evaluated to confirm that the constraints set forth in the scenario were satisfied and compare to the baseline scenario. Fourteen scenarios were submitted for the East-Side case study, resulting in 700 potential alignment outputs and twenty-two were submitted for the West-Side case study, resulting in 1100 potential alignment outputs.

The following sections describe the additional analyses that were performed on the East- and West-Side scenarios. It should be noted that alignment costs would not reflect actual construction costs, but rather provide a basis for comparison of costs between different alignments (i.e. baseline alignment construction cost only).

5.3 East-Side Case Study

5.3.1 *Baseline Scenario*

The East-Side baseline scenario, designated QRPH450, originated from the same base scenario file (QRPH407) as the West-Side baseline scenario (QRPH408). Fifty alignments were returned from Quantm that met the baseline scenario constraints (Figure 27). The spatial distribution of the alignments created two distinct corridors, one to the east of Standley Lake and the other to the west. Many of the routes have a similar location near the finish point due to the large percentage of Level 1 avoidance areas, where the only possible routes are along existing roadways.

Data output results for the East-Side baseline scenario, QRPH450, are listed in Table 4. Overall alignment lengths ranged from 15.3 to 19.5 miles, with an average length of 16.9 miles. Costs ranged from approximately $70 million (M) to $231 M with an average cost of $107 M. Cut and fill volumes were generally well balanced ranging from approximately 2 to 21 million cubic yards (My^3) each, with an average cut volume of 5.9 My^3 and average fill volume of 5.7 My^3. There were no extra costs in the baseline scenario since the NEPA special zones were ignored or avoided.

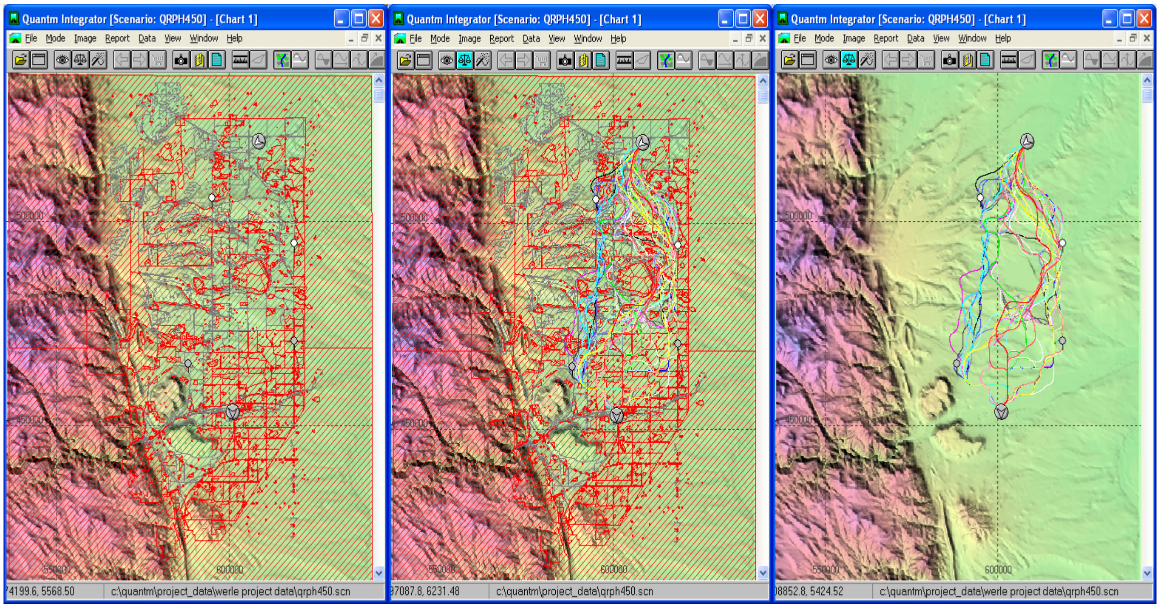


Figure 27:
East-Side Baseline (QRPH450)

Table 4: Summary of NEPA Scenario Outputs

Scenarios	RUN	SCENARIO	LENGTH (miles)			COST ($000)			EXTRA COST ($000)			EXTRA COST (acres)			Cut (x1,000,000 y3)			Fill ('x1,000,000 y3)		
			Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
West-Side Scenarios	QRPH408	Baseline	19.4	26.4	23.0	26.6	144.7	56.5	0	0	0	0.0	0.0	0.0	5.4	55.3	13.7	5.5	24.3	11.7
	QRPH409	Hazardous Materials Extra Cost	18.7	25.4	22.3	27.4	92.6	55.8	0	42,252	12,648	0.0	8.0	2.5	5.6	24.9	12.4	5.4	18.6	11.0
	QRPH410	Hazardous Materials Ignore	19.2	28.8	22.9	27.9	101.1	55.1	0	0	0	0.0	0.0	0.0	5.3	23.9	12.1	5.4	19.2	11.2
	QRPH411	Wetlands Avoid	19.2	26.8	23.1	27.2	98.4	54.6	0	0	0	0.0	0.0	0.0	6.8	30.5	13.6	7.1	23.9	12.4
	QRPH412	Wetlands Cost	19.0	26.1	22.6	26.7	104.1	54.9	152	2,101	637	2.0	21.0	6.3	5.3	44.5	13.8	5.4	40.7	12.5
	QRPH413	Preble Avoid	18.8	25.8	22.4	25.3	139.4	54.3	0	0	0	0.0	0.0	0.0	5.8	45.7	12.6	6.0	28.1	11.1
	QRPH414	Prebble Cost	19.3	25.9	23.0	30.5	81.4	53.9	506	6,246	1,887	5.0	62.0	18.9	5.7	26.5	13.2	5.6	21.1	11.9
	QRPH415	Prairie Dog Avoid	19.5	26.8	22.9	27.9	93.2	54.8	0	0	0	0.0	0.0	0.0	6.4	33.9	12.8	6.9	18.0	11.6
	QRPH416	Prairie Dog Cost	19.0	27.3	22.7	28.2	94.5	54.0	0	6,141	1,766	0.0	61.0	17.6	5.2	30.0	13.3	5.6	29.2	12.3
	QRPH417	Orchid Avoid	18.9	26.6	22.8	31.8	118.2	55.5	0	0	0	0.0	0.0	0.0	6.3	41.0	13.6	6.6	27.9	12.0
	QRPH418	Orchid Cost	18.9	27.4	21.9	26.0	99.8	50.9	0	602	208	0.0	6.0	2.2	5.5	28.4	11.5	5.4	20.3	10.7
	QRPH419	Landfills Avoid	19.0	26.3	22.5	27.7	96.2	53.2	0	0	0	0.0	0.0	0.0	5.2	27.0	12.1	5.2	19.7	11.1
	QRPH420	Landfills Cost	18.9	27.6	22.9	28.2	94.9	54.9	0	43,626	5,992	0.0	4.0	0.6	6.0	27.2	12.9	5.8	26.3	12.1
	QRPH421	Landfill CERCLA Ignore	18.6	26.2	21.9	29.4	104.0	55.3	0	0	0	0.0	0.0	0.0	5.9	46.2	14.7	5.2	29.4	12.6
	QRPH422	Landfill CERCLA Cost	18.9	25.8	22.4	24.6	104.2	57.6	0	97,921	12,017	0.0	10.0	1.2	5.6	33.9	12.3	6.0	30.8	11.2
	QRPH423	Surface Mines Avoid	19.0	27.7	22.9	28.9	88.2	54.1	0	0	0	0.0	0.0	0.0	6.0	25.4	12.5	6.5	20.3	11.5
	QRPH424	Surface Mines Cost	18.9	26.2	22.9	29.0	122.6	54.6	0	15,962	2,380	0.0	16.0	2.4	5.7	29.0	12.4	5.7	28.1	11.2
	QRPH425	L1-Residential Avoid	19.2	26.6	22.9	26.5	80.4	52.7	0	0	0	0.0	0.0	0.0	6.4	25.1	12.7	7.3	24.9	13.3
	QRPH426	L1-Residential Cost	18.6	26.4	23.0	40.7	151.6	77.3	60,141	210,673	90,135	120.0	421.0	180.3	5.4	37.3	14.3	6.5	37.2	12.4
	QRPH427	L1-Commercial Avoid	18.8	26.6	22.8	29.9	116.1	55.8	0	0	0	0.0	0.0	0.0	5.8	37.3	13.4	5.4	22.4	11.8
	QRPH428	L1-Commmercial Cost	18.5	26.2	22.9	40.8	102.4	71.1	39,093	117,668	80,544	39.0	118.0	80.6	5.9	26.8	12.2	5.7	20.6	11.6
	QRPH429	Combination	19.0	27.0	22.9	62.1	197.8	103.8	144,271	465,926	254,540	220.0	816.0	335.8	5.1	62.2	14.2	5.6	27.5	11.4
East-Side Scenarios	QRPH450	Baseline	15.3	19.5	16.9	13.2	43.8	20.2	0	0	0	0.0	0.0	0.0	2.4	21.2	5.9	2.1	20.7	5.8
	QRPH451	Hazardous Materials Extra Cost	14.5	20.8	16.7	15.8	36.3	22.4	1,108	63,429	17,989	0.0	13.0	3.6	2.1	11.1	5.1	1.9	10.8	5.1
	QRPH452	Hazardous Materials Ignore	13.9	19.1	16.8	12.5	31.9	18.3	0	0	0	0.0	0.0	0.0	2.3	12.0	4.9	2.1	12.4	4.7
	QRPH453	Orchids, Prarie Dog, and Prebles Avoid	14.6	19.4	17.0	12.2	29.0	19.6	0	0	0	0.0	0.0	0.0	2.2	11.9	5.9	2.1	11.7	5.4
	QRPH454	Orchids, Prarie Dog, and Prebles Cost	14.8	19.8	16.7	13.3	31.3	19.8	0	6,871	2,026	0.0	69.0	20.2	2.3	13.5	5.5	2.3	12.4	5.3
	QRPH455	Wetlands Avoid	15.2	20.3	16.9	12.3	28.7	19.6	0	0	0	0.0	0.0	0.0	2.0	10.3	5.7	2.0	10.4	5.4
	QRPH456	Wetlands Cost	14.9	19.0	16.8	13.3	34.5	18.7	58	1,298	416	1.0	13.0	4.2	2.4	13.4	5.2	2.5	13.3	4.9
	QRPH457	Landfills and Surface Mines Avoid	14.9	19.9	17.3	14.1	33.9	18.3	0	0	0	0.0	0.0	0.0	2.7	12.7	4.9	2.1	13.3	4.6
	QRPH458	Landfills and Surface Mines Cost	15.3	20.1	17.1	14.3	34.7	19.6	0	17,797	948	0.0	2.0	0.1	2.5	13.1	5.5	2.5	13.7	5.2
	QRPH459	L1-Residential Avoid	15.3	19.8	17.2	15.5	36.7	22.8	0	0	0	0.0	0.0	0.0	3.4	11.4	6.9	2.6	13.3	6.8
	QRPH460	L1-Residential Cost	14.8	18.8	16.4	21.9	55.4	31.8	25,382	126,036	73,628	51.0	252.0	147.3	2.4	17.3	4.8	1.9	16.6	4.4
	QRPH462	L1-Commercial Avoid	15.1	20.7	17.2	13.2	30.3	18.7	0	0	0	0.0	0.0	0.0	2.4	11.7	5.2	2.3	11.2	5.0
	QRPH463	L1-Commercial Cost	15.2	19.3	16.7	13.8	33.9	22.2	0	81,466	22,388	0.0	81.0	22.4	2.3	9.9	4.9	2.0	10.0	4.5
	QRPH464	Combination	14.1	20.5	16.8	29.6	58.9	44.7	58,227	207,427	136,754	74.0	336.0	206.2	2.2	12.7	5.1	2.2	13.3	4.8

5.3.2 *Scenario Testing*

Twelve scenarios were created to test the effects of varying NEPA special zones on East-Side alignments developed by Quantm. Scenarios QRPH451 to QRPH463 (there was no QRPH461) were incrementally changed from the baseline scenario QRPH450 to test the effects of the change on Quantm data outputs for length, cost, and volumes of cut and fill. Scenario data outputs are provided in Appendix A.

Table 5 provides a comparison of Quantm outputs in relation to the baseline values for length, cost, and volumes of cut and fill. For example, the table shows that by changing the baseline condition of hazardous material sites from avoidance (baseline) to an extra cost, the overall average length of alignments produced by Quantm were reduced more than 1,000 ft. Similarly, overall average costs for alignments increased by more than $11 M under this same scenario.

Table 5: East-Side Scenario Testing Results

Scenario	Assumption	Average Change from Baseline QRPH450			
		Length (feet)	Cost ($000)	Cut ('000 y3)	Fill ('000 y3)
QRPH451	Hazardous Materials Extra Cost	↓ 1,093	↑ 11,373	↓ 782	↓ 723
QRPH452	Hazardous Materials Ignore	↓ 392	↓ 9,810	↓ 1,025	↓ 1,031
QRPH453	Orchids, Prairie Dog, and Prebles Mouse Avoid	↑ 519	↓ 3,266	↓ 51	↓ 348
QRPH454	Orchids, Prairie Dog, and Prebles Mouse Extra Cost	↓ 1,016	↓ 1,938	↓ 416	↓ 488
QRPH455	Wetlands Avoid	↑ 228	↓ 3,207	↓ 215	↓ 334
QRPH456	Wetlands Extra Cost	↓ 504	↓ 7,977	↓ 711	↓ 869
QRPH457	Landfills and Surface Mines Avoid	↑ 1,967	↓ 10,068	↓ 1,051	↓ 1,147
QRPH458	Landfills and Surface Mines Extra Cost	↑ 1,127	↓ 3,461	↓ 425	↓ 525
QRPH459	L1- Residential Avoid	↑ 1,690	↑13,856	↑950	↑993
QRPH460	L1-Residential Extra Cost	↓ 2,600	↑61,302	↓ 1,087	↓ 1,358
QRPH462	L1-Commercial Avoid	↑ 1,688	↓ 7,910	↓ 723	↓ 811
QRPH463	L1-Commercial Extra Cost	↓ 1,157	↑10,311	↓ 1,057	↓ 1,304

General observations noted from this testing include:

- Use of avoidance special zones generally increases the overall length, cost, and volumes of cut and fill of Quantm alignments.
- In some cases (residential and commercial), changing special zones from ignore to extra cost resulted in decreasing average alignment length and cut and fill volumes, but increased average costs. In other cases (biological and wetlands), changing special zones from ignore to extra costs resulted in decreasing average alignment length, cut and fill volumes, and cost.
- Special zones that cover a large percentage of a study area, such as residential land use, have the greatest impact on the length, cost, and volume of cut and fill of Quantm alignments. Similarly, special zones that cover a small percentage of a study area, such as wetlands, have the least impact on the length, cost, and volume of cut and fill of Quantm alignments.

5.3.3 *Hypothetical NEPA Combination Scenario*

The East-Side hypothetical NEPA combination scenario, designated QRPH464, originated from the baseline scenario file (QRPH450), with the addition of special zones listed in Table 2. Fifty alignments were returned from Quantm that met the NEPA combination scenario constraints (Figure 28). The spatial distribution of the alignments was similar to the baseline scenario in that two distinct corridors were created, one to the east of Standley Lake and the other to the west. Unlike the baseline scenario, where the location of the alignments near the finish point was very similar, the combination scenario had numerous linear segments throughout the entire alignment length. This result is explained by the larger percentage of avoidance and extra cost areas in the combination scenario, which constrained alignments to existing roadways.

Data output results for the East-Side hypothetical NEPA combination scenario, QRPH464, are listed in Appendix A. Overall alignment lengths ranged from approximately 14.1 to 20.5 miles, with an average length of 16.8 miles. For comparison purposes, costs ranged from \$157 M to \$311 M with an average cost of \$236 M. Cut and fill volumes were generally well balanced ranging from approximately 2 to 13 million cubic yards (My^3) each, with an average cut volume of 5.1 $My^3$and average fill volume of 4.8 My^3. Extra costs for the NEPA combination scenario included an average of 206 acres or \$136 M of impacted special zones.

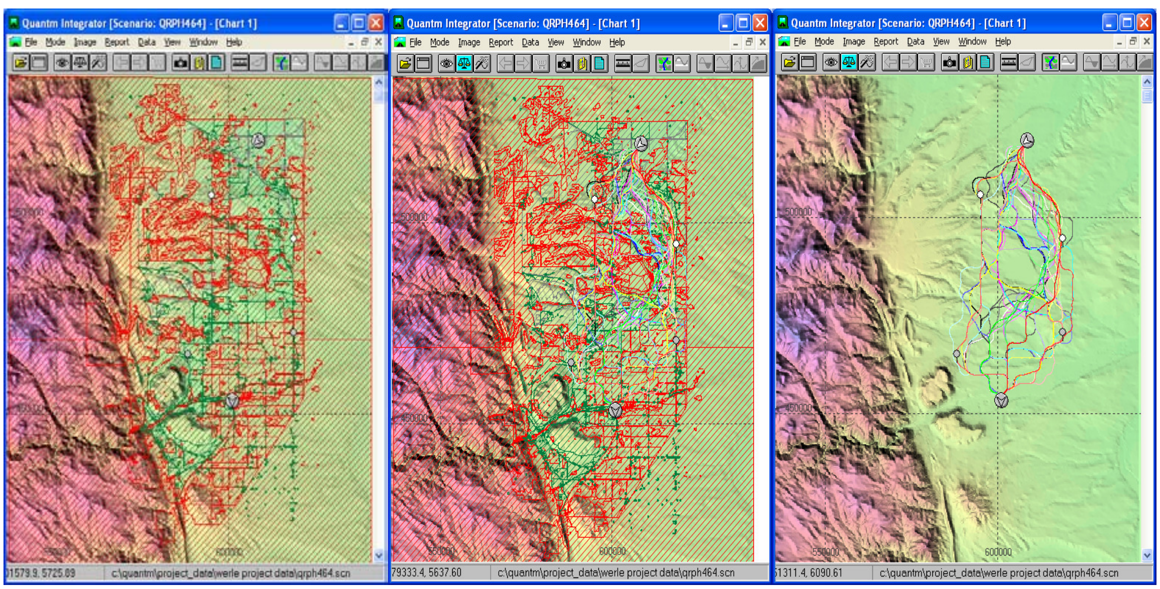


Figure 28:
East-Side Hypothetical NEPA Combination Scenario (QRPH464)

A graphical side-by-side comparison of the baseline (Pre-NEPA) and hypothetical NEPA combination scenarios is provided in Figure 29. The comparison depicts the increase in straight portions of the alignments under the NEPA combination scenario. Comparison of data outputs reveals an overall decrease in average lengths from the baseline to the NEPA combination of approximately 600 ft (Appendix A). Average cut and fill volumes similarly decreased from the baseline to the NEPA combination scenario by 0.8 and 0.9 My^3, respectively. This result is somewhat unexpected since additional constraints typically increase Quantm alignment length and cut and fill volume. However, with more constraints in the urban portions of the study area, the alignments are forced to follow existing roadways where new cut and fill would likely be needed less. As anticipated, average costs for the hypothetical NEPA combination scenario ($236 M) were substantially greater than the average baseline scenario ($106 M) with the addition of extra cost special zones.

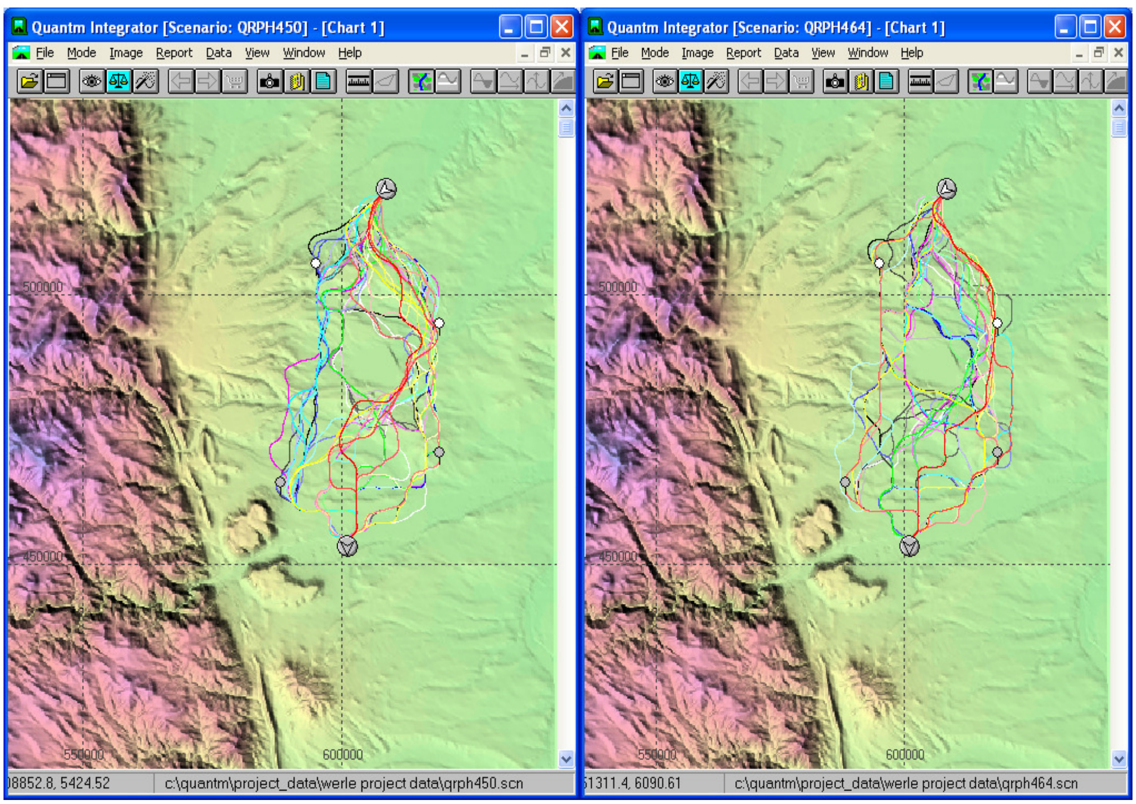


Figure 29:
Comparison of Baseline (left) and NEPA Combination (right) Scenarios

Comparison of data outputs from the hypothetical NEPA combination scenario, QRPH464, allowed the evaluation team to consider an optimal alignment in terms of length, cost, cut and fill volumes, and extra costs as measured by impacted acres. This comparison revealed that alignment QRPH464_34 had the second lowest cost ($158 M), cut and fill volumes that were below the average (4.1 and 4.1 My^3, respectively), and lowest impacted acres (74 acres). Alignment QRPH464_34 is depicted in Figure 30.

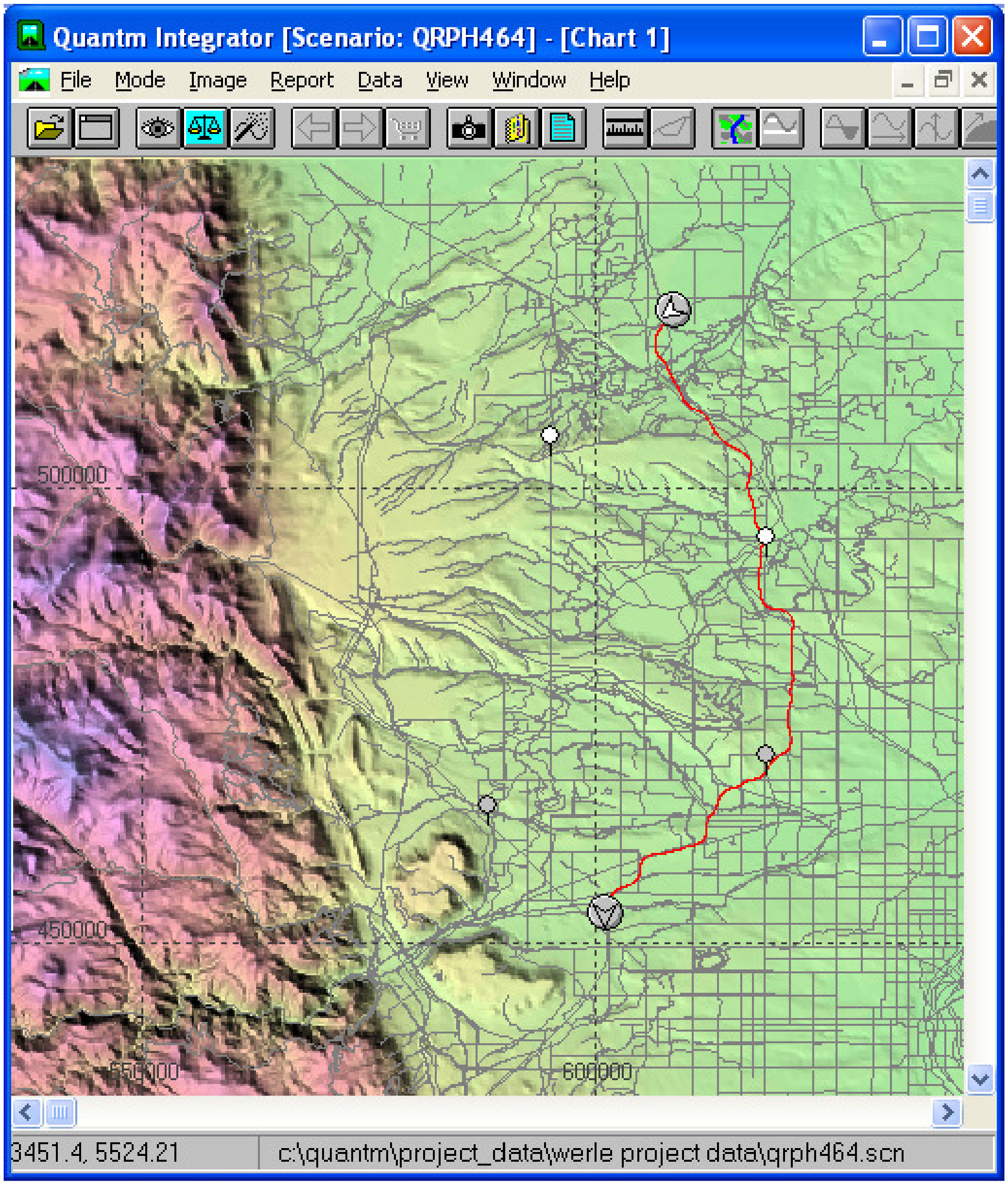


Figure 30:
Optimal East-Side Hypothetical NEPA Combination Alignment, QRPH464_34

5.4 West-Side Case Study

The West-Side baseline scenario, designated QRPH408, originated from the same base scenario file (QRPH407) as the East-Side baseline scenario (QRPH450). Fifty alignments were returned from Quantm that met the baseline scenario constraints. The returned alignments tended to form two distinct corridors, one to the west of the former Rocky Flats nuclear weapons facility and the other to the east. The topology of the West side's southern terminus is dominated by North and South Table Mountains. The West side is characterized by having generally less residential land than the East side. There were no extra costs in the West-Side baseline scenario since the NEPA special zones were ignored or avoided. Data output results for the West-Side baseline scenario, QRPH408, are listed in the output table in Appendix D.

Results of testing the various NEPA special zones for the West-Side case study did not vary significantly from results presented for the East-Side case study. While there were a number of geographically different alignments, the variation of length, cost, and cut and fill volumes from the baseline scenario were not significantly different than the East-Side results. Therefore, the evaluation team did not further summarize the data results or findings for the West-Side case study

5.5 Additional Studies

This section describes additional testing that was performed to determine which layers had the greatest impact on Quantm alignment development.

5.5.1 *Influence of Data Layers on Alignment Output*

The project team tested the effects of varying the designation (i.e. avoidance, extra cost, or ignore) of NEPA special zones on the overall length, cost, extra cost (in terms of acres), and cut and fill volumes of alignments produced by Quantm. In the Quantm comparison mode, the output file can be saved directly as an Excel spreadsheet (.CSV file) that compiles the results for all 50 alignments (or a user selected subset) within the scenario. Then the maximum, minimum, and average values can be calculated for each scenario.

The benefit of this analysis is that it allows the user to quickly identify NEPA special zones that create a substantial impact to the alignments. For example, it will be shown that by making incremental changes to the designation (avoid or extra cost) of each NEPA special zone, it was determined that residential land use had the most significant impact on alignment length, cost, and cut and fill volumes. Then, by selectively designating specific residential locations as either avoidance or as an extra cost, a scenario can be produced that optimizes average values of alignment length, cost, and cut and fill volumes.

An evaluation of the effects of NEPA special zones on length, cost, extra cost (in terms of acres), and cut and fill volumes is provided below. The East-Side scenario runs were used in the evaluation for simplicity. As in the rest of the Quantm analysis, cost values do not represent actual cost estimates, but rather provide a basis cost comparison between alignments.

Length. Figure 31 shows that average alignment lengths varied from 86,500 feet (16.4 miles) to 91,100 feet (17.3 miles). The length of the baseline scenario was 89,100 (16.9 miles). The NEPA special zone that had the greatest effect on length was residential land use, which when changed from an avoidance area to an extra cost reduced the average length of roadway alignments by nearly one mile (a 6 percent reduction). This result is not unanticipated since residential land use covers a large portion of the study area. In general, scenarios with special zones identified as avoidance areas resulted in longer alignments.

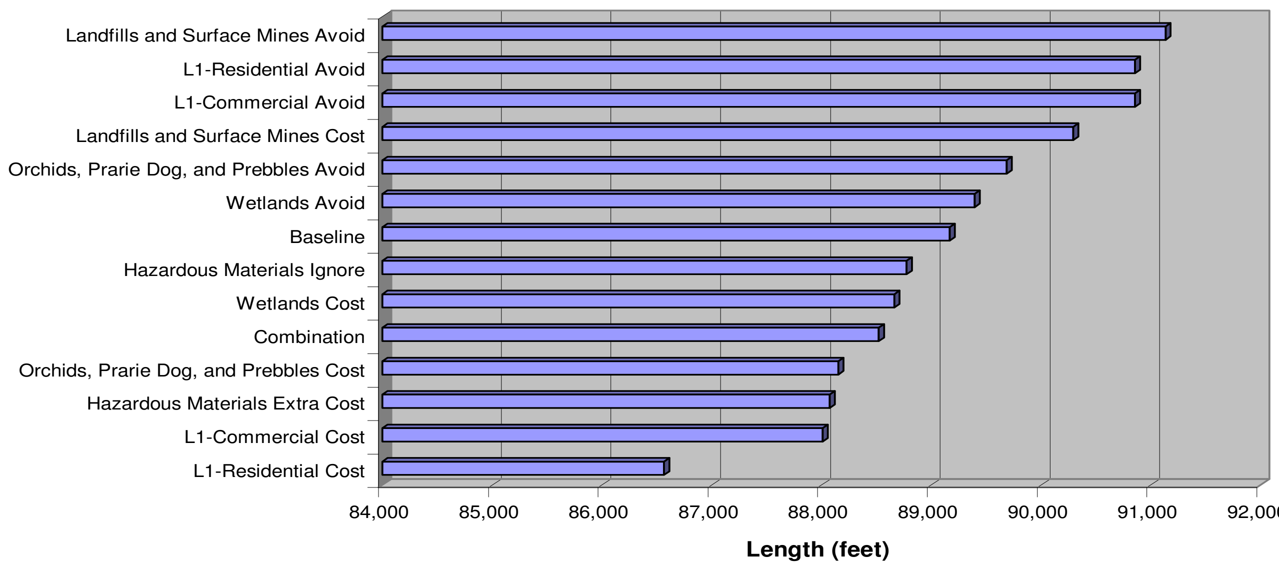


Figure 31:
Effects of Special Zones on Alignment Length

Cost. Figure 32 shows that average alignment costs varied from \$96.2 million (M) to \$235.8 M, with the Baseline scenario at \$106.6M. Overall, costs were moderately influenced by changing classifications of individual NEPA factors from avoid and ignore to cost. Costs were generally within 10 percent of the Baseline scenario, with the exception of the residential cost and hypothetical NEPA combination scenarios. As noted above regarding alignment length, allowing alignments to cross residential areas can reduce length by 6 percent, but as observed here, can increase overall project costs by more than 50 percent. With the addition of residential and commercial cost special zones, the combination scenario is predictably the most expensive (but more reflective of realistic conditions).

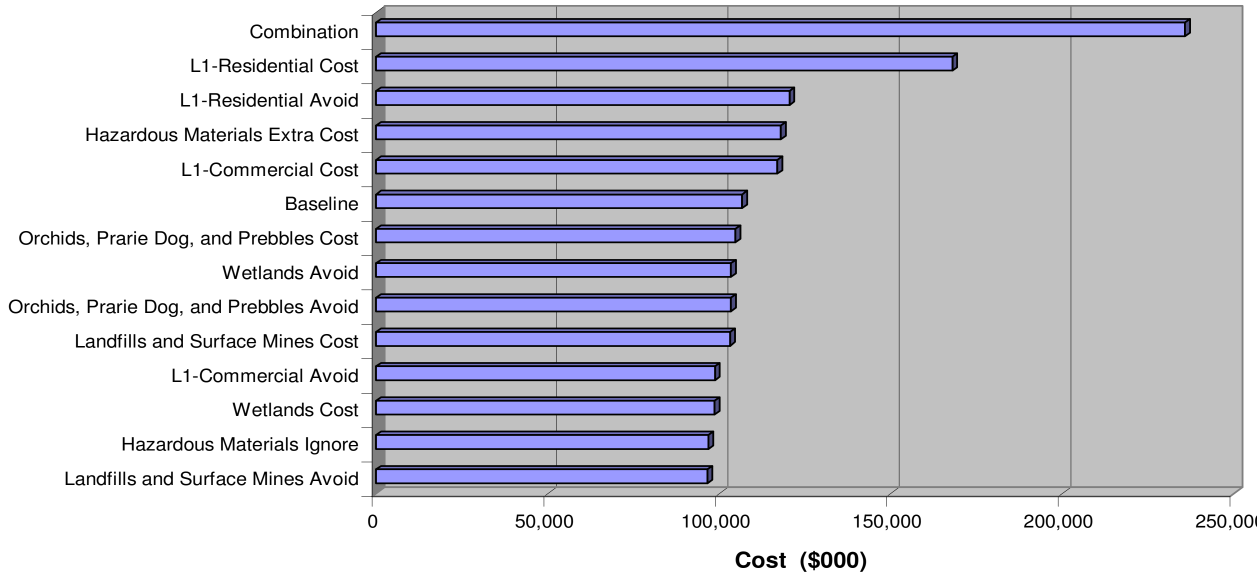


Figure 32:
Effect of Special Zones on Cost

Impacted Area (Acres). Only by designating a special zone as an extra cost feature will the spreadsheet summary of Quantm's output identify the amount of acres impacted. There are no extra costs (acres) from avoid areas since Quantm successfully identified alignment routes around these areas (Figure 33). By testing the extra cost feature of each scenario separately from the Baseline scenario, the amount of acres of a specific NEPA resource can be estimated. For example, the baseline scenario ignores wetlands. By designating wetlands as an extra cost, Quantm estimates that an average of 4 acres of wetlands will be impacted by all 50 of the alignments considered under that scenario. Similarly, identifying residential areas as an extra cost, reveals that an average of approximately 150 acres of residential land use would be impacted under that scenario. The amount of impacted acres under the hypothetical NEPA combination scenario is essentially a sum of extra cost scenarios for residential, commercial, biological, wetlands, and hazardous materials.

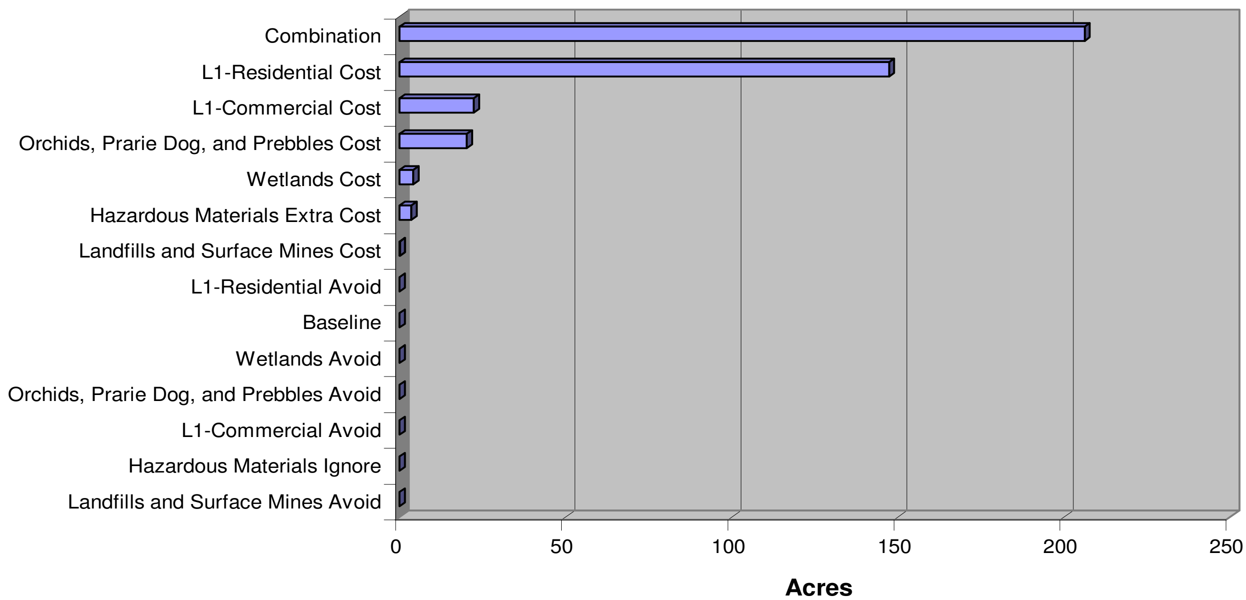


Figure 33:
Effect of Special Zones on Impacted Area (acres)

Volume of Cut. Figure 34 reveals that cut volumes range from 4.8 M cubic yards (y^3) to 6.8 M y^3. The Baseline scenario generated 5.9 M y^3 of cut material. The NEPA factor that had the greatest effect on cut volumes was residential land use, which by making a cost factor verses an avoidance factor, reduced the average amount of cut by 2 M y^3 (nearly 30 percent). In general, scenarios with the largest avoidance areas had the greatest amount of cut generated.

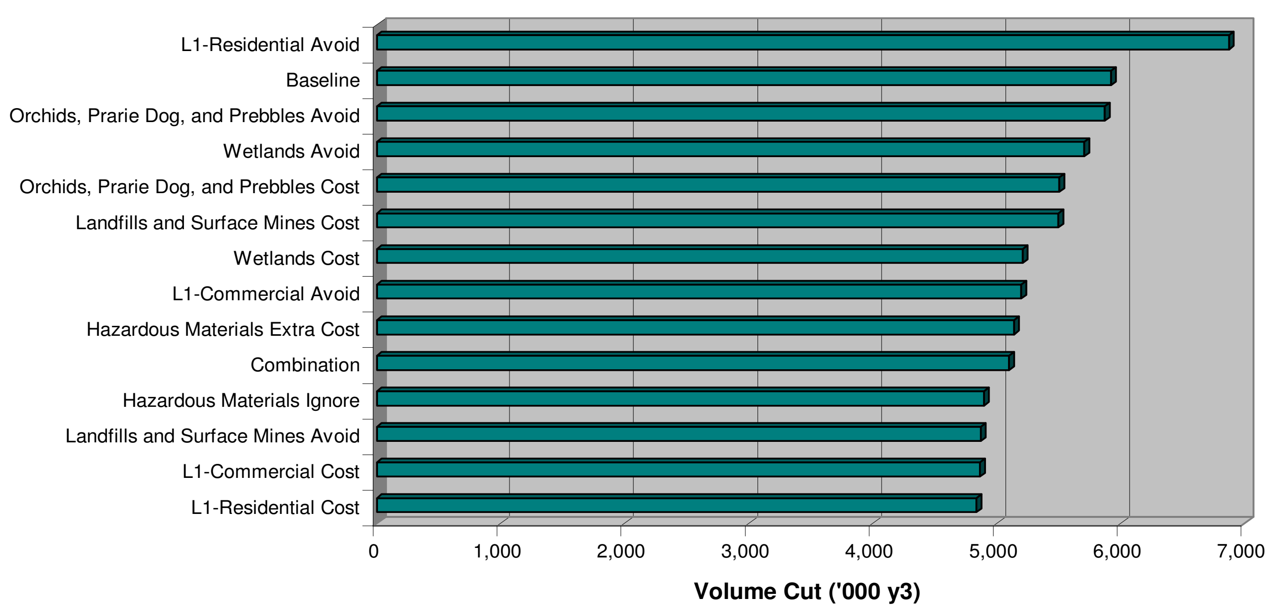


Figure 34:
Effect of Special Zones on Volume of Cut

Volume of Fill. Fill volumes were fairly well balanced with cut volumes for each scenario, with scenarios such as avoidance of residential areas having both the greatest cut and fill volumes. As with cut volumes, the residential scenario had the greatest impact on fill volumes, with reductions of 2.3 M y^3 (36 percent) by changing from an avoidance area to an extra cost area.

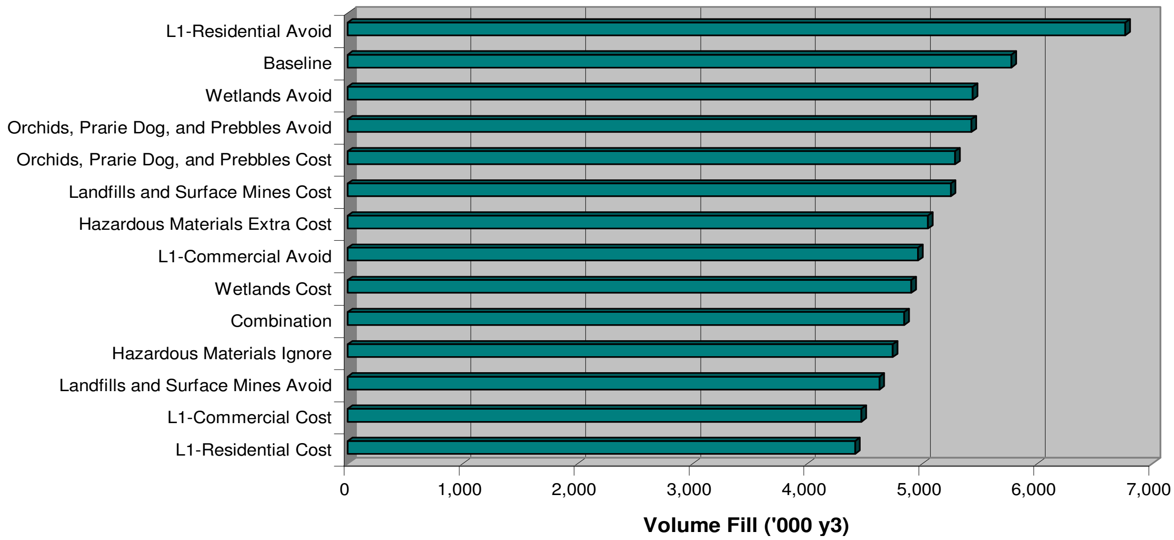


Figure 34:
Effect of Special Zones on Volume of Fill

5.5.2 *Engineering Studies*

One of the features Quantm provides is the flexibility to work with data from computer-aided drafting and design (CADD) software. Quantm allows the user to import individual alignments into CADD software and the reverse process of taking a CADD design and importing it into Quantm.

This study used CDOT's current platforms of MicroStation (CADD software) and InRoads (design software) as comparison tools. To use a Quantm alignment for design in InRoads, it is necessary to convert the 3D string of tangents that Quantm produces into a design of tangents and curves both horizontally and vertically that fit the engineering design parameters. The unit costs of earthwork, bridges, walls and roadway pavement were based on the latest Case Study project estimates.

The alignment chosen for this comparison study lies in the west corridor and is one of the routes undergoing preliminary design in the Case Study project. Using the horizontal and vertical design provided by the Case Study team, a 3D alignment was created in InRoads and exported out as a .dxf file. This file was sent to Quantm, processed, and returned as a linear feature. The linear feature was then loaded into the NEPA scenario in Quantm Integrator (Figure 35).

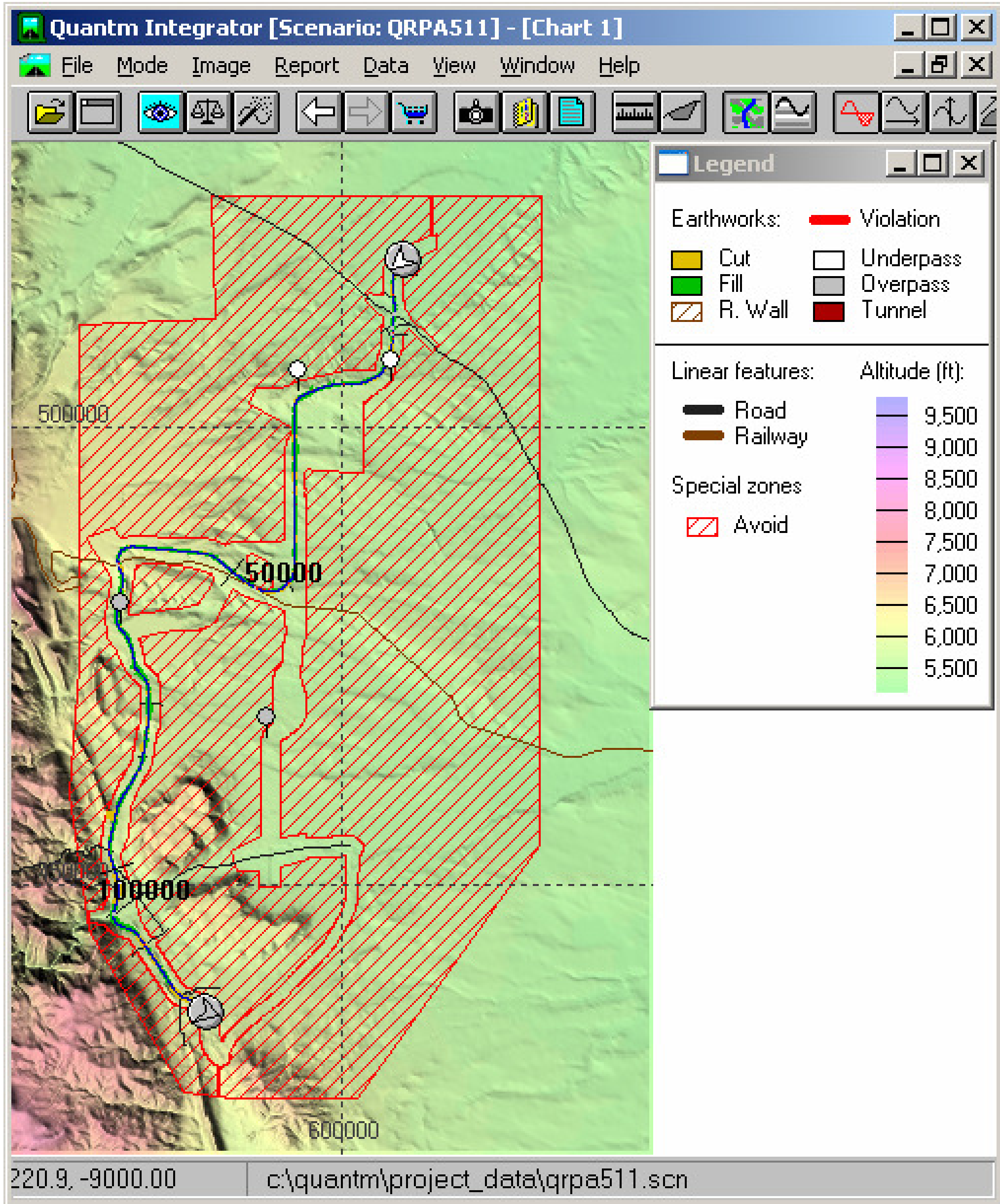


Figure 35: West Corridor Seed Alignment

A seed alignment was created from the linear feature using the arterial parameters for the west corridor from the Pre-NEPA study. Some final adjustments to costs and design parameters were made to match the latest changes in the Case Study project. Crossings of existing features that required grade separations (underpasses or overpasses) or at-grade-crossings were identified from the Case Study and entered into Quantm. This was accomplished by choosing the linear feature in Quantm and defining the crossing type and clearance in the linear feature file. The alignment was then optimized using the Quantm options of total refinement, total intensive refinement, and vertical refinement. The seed and optimized alignments were checked against the CADD package for compatibility of earthworks values, and the results of the refinements were investigated for potential savings in construction costs of the west-side alignment. The following sections describe the results of this analysis.

5.5.2.1 CADD Comparison

Using the alignment that was selected for this analysis, an earthwork model was created in InRoads that produced cut and fill quantities. These quantities are shown in Table 6, with the cut and fill quantities produced by Quantm for the same alignment. Also included are the earthwork values for selected alignments from each refinement.

As shown in Table 6, the Quantm cut numbers vary from 9% - 25% below InRoads values while the fill numbers vary from 0% - 2% greater than InRoads values. The major reason for the differences in cut was determined to be that Quantm inserted retaining walls in some locations to reduce the amount of cut, while such retaining walls were not modeled in InRoads.

Table 6: Comparison of Cut and Fill between Quantm and InRoads

Optimization		Quantm (x 1,000,000 y^3)	InRoads (x 1,000,000 y^3)	Quantm % Difference
Seed Alignment	Cut	4.55	5.71	25% low
	Fill	11.05	10.93	1% high
Total Refinement	Cut	8.08	8.80	9% low
	Fill	6.39	6.29	1% high
Total Intensive Refinement	Cut	7.66	9.39	23% low
	Fill	7.02	6.90	2% high
Vertical Refinement	Cut	12.52	13.77	10% low
	Fill	9.53	9.51	No change

In general, Quantm and CADD were very compatible and the comparisons could be done quickly. The discrepancy in quantities seems to reflect a difference in the DEM in Quantm and the creation of the terrain model in InRoads from the DEM (which is a triangulated irregular network, or TIN). A comparison of Quantm cross sections with InRoads cross sections shows that slight changes in the existing ground occurring near the steeper terrain can cause the proposed ground to either match existing ground near the roadway (Quantm) or extend up and parallel the existing ground creating a larger cut (InRoads). With additional effort, an engineer could overlay the InRoads earthwork limits with the earthwork footprint from Quantm and identify these areas and make adjustments to the model or the individual cross sections (resulting in closer agreement between Quantm and CADD).

5.5.2.2 Optimization Results

The alignment selected for this analysis was optimized using Quantm's refinement operations. As stated previously, each refinement creates twenty (20) new alignments. The new alignments can vary horizontally and vertically with the total and total intensive refinement, and vertically only with the vertical refinement. It should be noted that the refinements were performed on a preliminary (15% design alignment), and were constrained only by the major grade separations and at-grade-crossings that were a part of that preliminary design. Because only rough constraints were included in the refinements, any potential cost savings indicated by Quantm would have to be confirmed by further engineering studies that are not within the scope of this report.

Total Refinement

The total refinement optimizes the seed alignment horizontally and vertically by choosing new routes near the seed alignment. In the west corridor, the refined alignments were within 0.5 mile of the seed alignment (Figure 36). The new alignments created significant savings by combining changes to the overall length (base cost of roadway) with balanced earthwork.

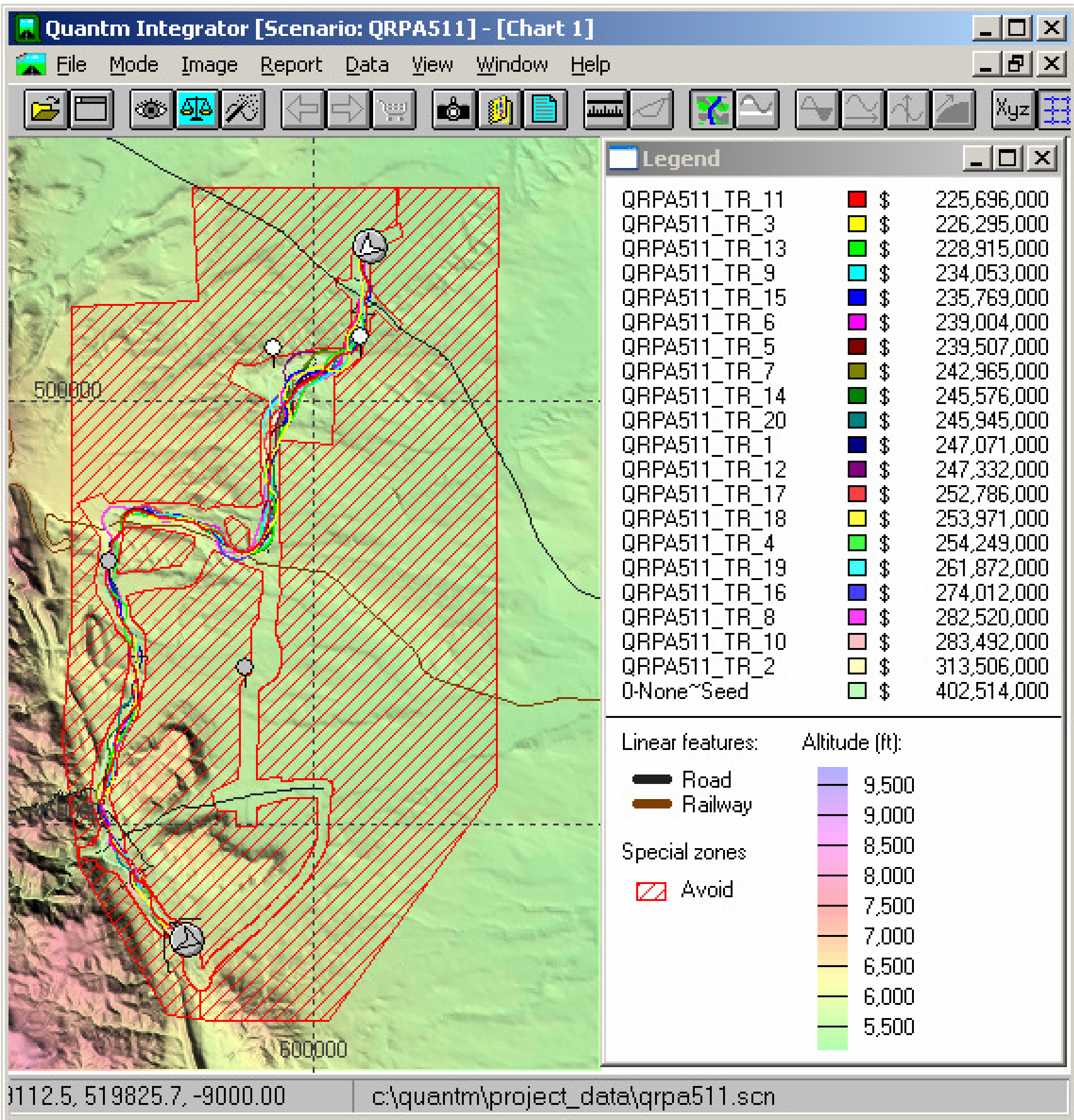


Figure 36: West Corridor Total Refinement

Total Intensive Refinement

The total intensive refinement also refines the seed alignment horizontally and vertically, but searches for new routes much closer to the seed alignment (Figure 37). Since this produces only minor shifts in the alignment, the costs for roadway, bridge and wall remain fairly constant among the options generated. The low to high costs are more a reflection in changes in cut, fill and earthwork haul values.

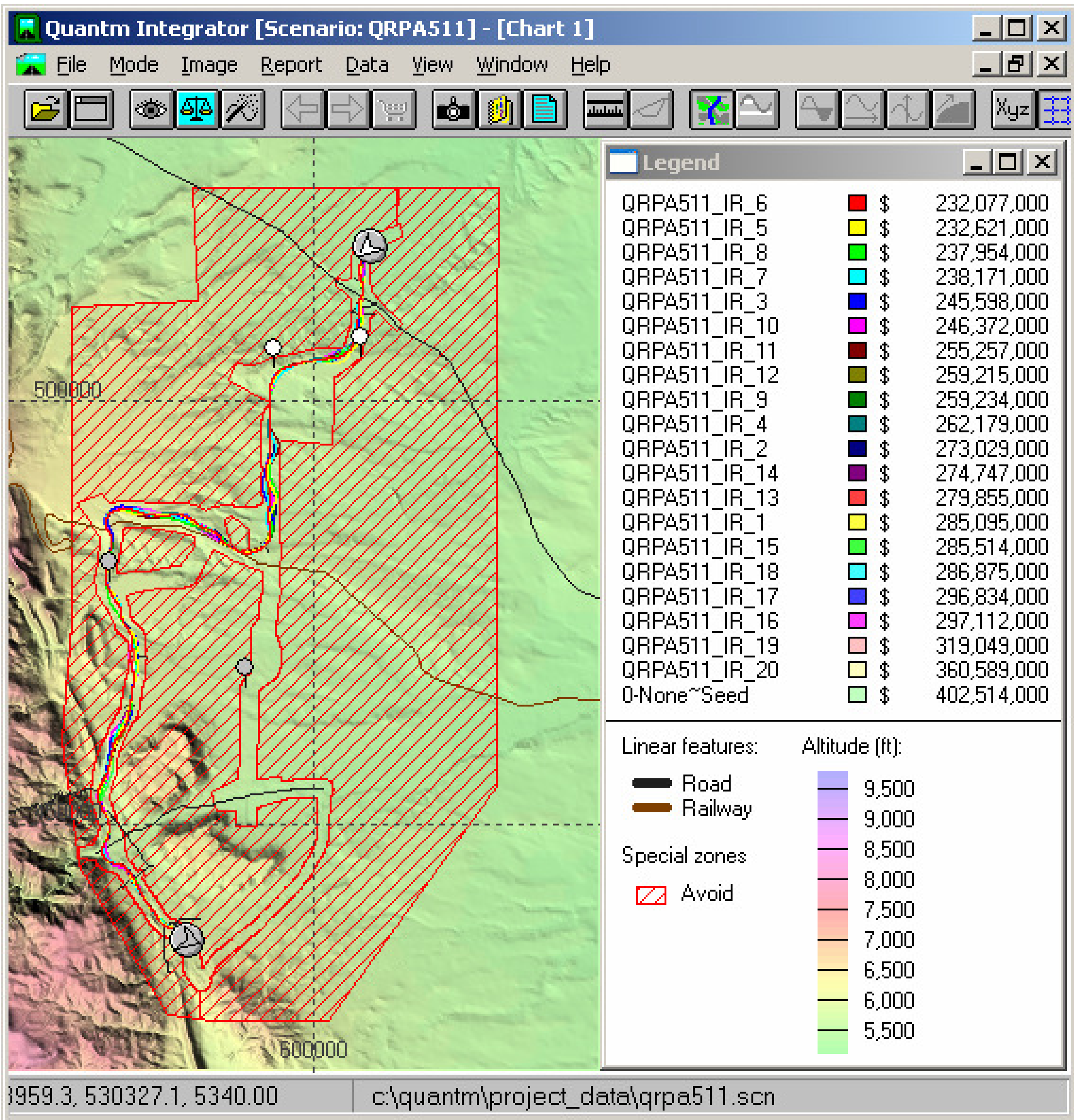


Figure 37: West Corridor Total Intensive Refinement

Vertical Refinement

The vertical refinement optimizes the seed alignment only in the vertical direction and the range of costs are due to cut, fill and earthwork haul values (Figure 38).

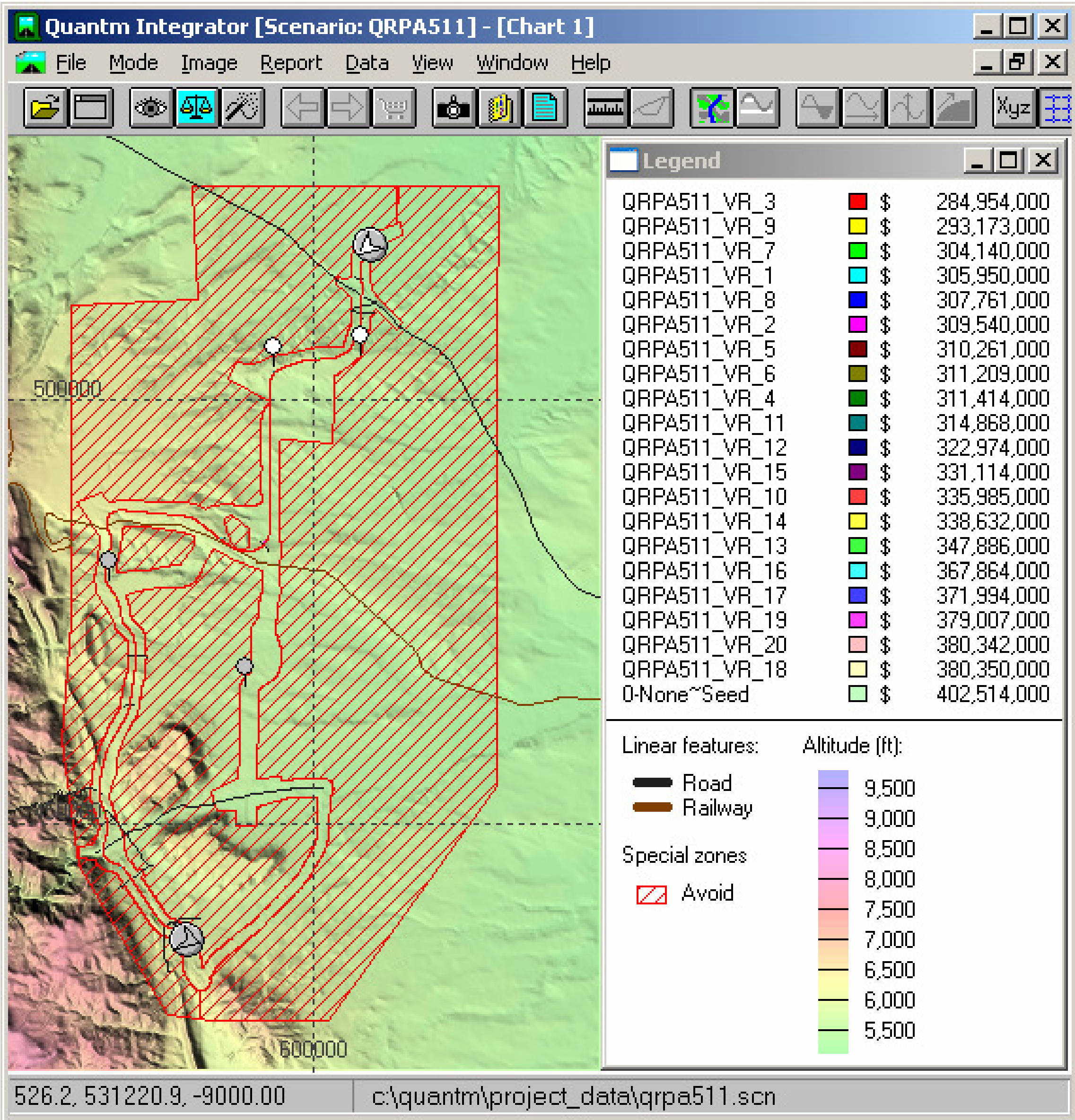


Figure 38: West Corridor Vertical Refinement

Local Refinement

The local refinement is used to refine a portion of the overall alignment. It can be used to optimize an alignment or introduce new constraints to a particular area of the alignment. For this study an 8 mile section was identified near the middle of the overall alignment as an area that could vary in location and elevation (Figure 39). Similar to the total refinement, the local refinement creates savings in all aspects of the overall cost.

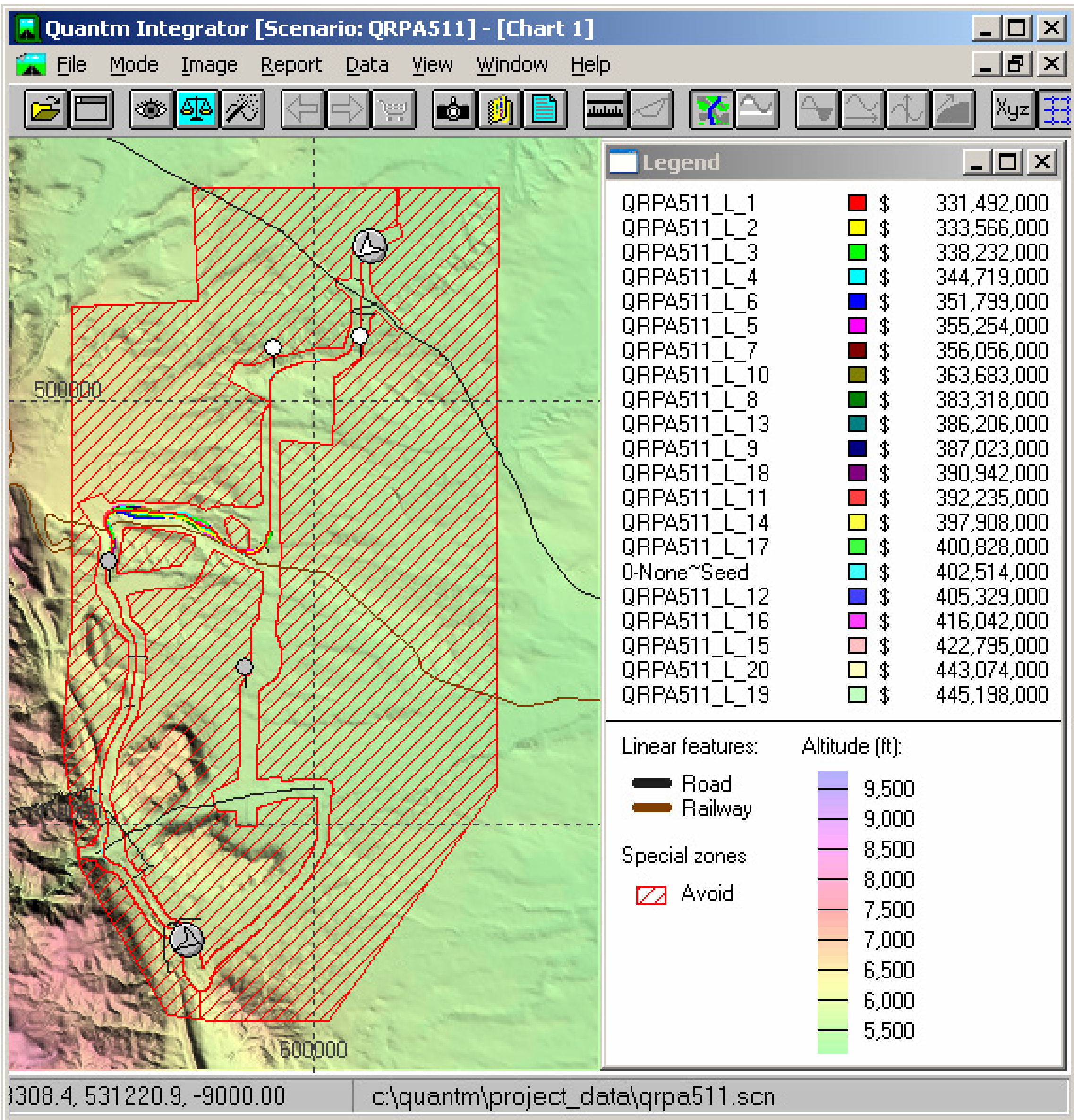


Figure 39: West Corridor Local Refinement

Table 7 compares the seed alignment with the highest and lowest cost alignments for each type of refinement.

Table 7: High and Low Costs for Quantm Refinements

	Total Refinement (millions)	Total Intensive Refinement (millions)	Vertical Refinement (millions)	Local Refinement (millions)
Low	$226	$232	$285	$331
High	$313	$361	$380	$445
Seed	$402	$402	$402	$402
Range of Savings (%)	22% - 44%	10% - 42%	6 - 29%	0% - 18%

As shown in Table 6, Quantm can provide significant reduction in the cost by refining an alignment. Therefore, we conclude that when a useable alignment is identified, the use of Quantm's refinements to reduce construction costs is immediate. Without Quantm, a time-consuming process of comparing horizontal and vertical alignments to find the optimum balance between earthwork and overall length would be necessary.

The largest variation in one item was the mass haul. The mass haul is defined as the cumulative earthwork volume moved along an alignment. This number varied significantly among the 20 alignments in each refinement. The mass haul diagram that Quantm creates identifies balances and long hauls (Figure 40). While Quantm may balance earthwork quantities, the overall movement of soil may increase. For instance, if the majority of cut work is at the north end of the project and fill is needed at the south end, a large cost is incurred to transport the soil that distance. In a project of this length, the actual construction may be done in phases to help offset the flow of earthwork throughout the corridor (thus reducing the mass haul quantity).

Alternatively, there an option to add constraints to the movement of earthworks by defining "barriers." For example, a stream may be defined as a barrier to the movement of earthworks such that the system endeavors to balance earthworks on either side of the barrier. There is also the option of defining source and sink volumes within each segment being considered. These features may be helpful on a real project application where these options could be explored within the context of the specific project but it was felt that this would not have significantly contributed to this Case Study project.

Another aspect of this design, located in an urban setting with many existing roads, is the importance of at-grade crossings. Many of the existing cross roads need to remain, and the vertical alignment of the Case Study needs to reflect only slight elevation differences at these crossings. Quantm does allow for at-grade restrictions across linear features and a value of +/- 1 foot was used for this study.

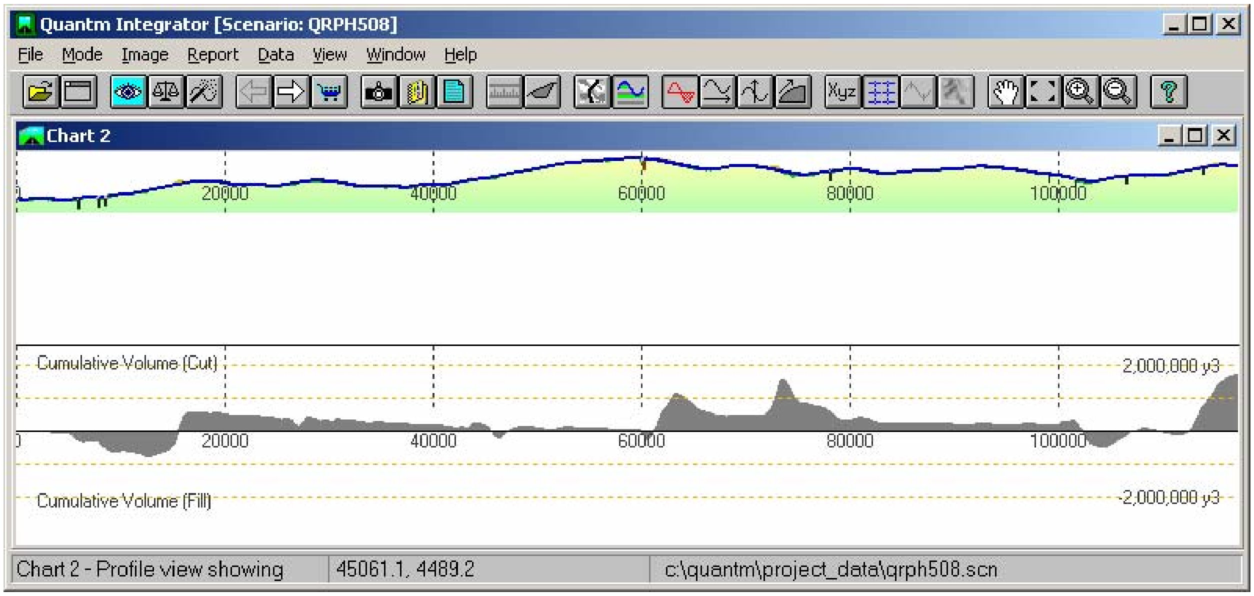


Figure 40: Quantm Alignment Profile (top) and Mass Haul Diagram (below)

NEPA Findings/Observations

Table 8 identifies the usefulness of NEPA GIS data layers, including whether they were used in Quantm, the type of Quantm data created from the layer, and notes on each layer.

Table 8: Usefulness of NEPA Data Layers for Quantm Analysis

	Used In Study	Type of Quantm Data	Usefulness	Notes
Base Map				
USGS DEM	YES	Terrain Model	HIGH	Critical to Quantm function; higher resolution helpful for specific NEPA planning
Aerial Photograph	YES	Background Image	HIGH	Very helpful for reference & orientation, heads-up digitizing of manmade facilities
Functional Class Roads	YES	Linear Feature	HIGH	Important reference layer - buffered to "cut out" existing roadways
Highways	YES	Linear Feature	HIGH	Important reference layer - buffered to "cut out" existing roadways
Railroads	YES	Linear Feature	HIGH	Important reference layer
Rocky Flats Boundary	YES	Special Zone	HIGH	Example of an avoidance area that is known from project outset (Level 1 regional avoidance)
Table Mesa Boundaries	YES	Special Zone	HIGH	Example of a special zone that is known from project outset
Counties	NO	Special Zone	MEDIUM	County Boundaries were not needed for Quantm analysis but serve as reference layers in GIS
City Boundaries	NO	Special Zone	MEDIUM	City Boundaries were not needed for Quantm analysis but serve as reference layers in GIS
Bridges	NO	Special Zone (buffered points)	LOW	At the planning stage, not needed for Quantm analysis
Bike Trails	NO	Linear Feature	LOW	Can be useful for Quantm NEPA analysis, but output difficult to evaluate
Geology				
Sand & Gravel	NO	Geology	MEDIUM	Probably not needed for NEPA planning work, but could help in engineering phase
Hydrology				
Lakes and Reservoirs	YES	Special Zone	HIGH	Generally avoidance areas (otherwise bridge/viaduct crossing)
Streams and Rivers	YES	Linear Feature	HIGH	Important NEPA reference layer, can be used for linear features
Q3 Floodplain Data	YES	Special Zone	MEDIUM	Could be used to identify extra construction costs for flooding mitigation
Flora/Fauna				
T&E Species Habitat	YES	Special Zone	HIGH	Preliminary data may be inaccurate enough to be misleading – best as NEPA data
Wetlands	Yes	Special Zone	HIGH	National wetlands inventory is generally inaccurate enough to be misleading – best as NEPA data
Land Use				
Visual Corridors	YES	Special Zone	MEDIUM	Could be used as avoidance areas
City/County Parcels	NO	Special Zone	LOW	Too much detail for planning portion of study
Parks and Rec Areas	YES	Special Zone	HIGH	Parks and Rec areas were used in Quantm analysis as either avoidance zones or extra cost zones
City and County Land Use Layers	YES	Special Zone	HIGH	Residential land uses cover a majority of the study area and substantial impacts alignment route, length, and cost.
City and County	YES	Special Zone	MEDIUM	Zoning codes were inconsistent but were merged

Zoning Layers				into one layer – difficult to simplify
Open Space	YES		HIGH	
Other				
COGCC Oil and Gas Facilities data set	YES	Special Zones (buffered points)	MEDIUM	Although small, these locations could be used as avoidance areas
Hazardous Materials Sites	YES	Special Zone	MEDIUM	Numerous small sites can impact costs and feasibility.
Landfills	YES	Special Zone	MEDIUM	Large sites can have regional influence on alignments
Underground Coal Mines	YES	Special Zone	MEDIUM	Geotechnical issues can significantly impact costs.

The following are the key observations of the evaluation team at the completion of the NEPA analysis:

- Transportation improvements often involve multi-modal alignments. Each mode has specific needs and must run independently and concurrently with other modes. Quantm does not consider dual modes of transportation, and therefore users must analyze rail and roadway alignments separately.

- The consideration and testing of different scenarios is often a time-consuming step in the alignment development process. Quantm provides a tool to quickly test different scenarios by varying assumptions and comparing results, usually on a next-day basis. For example, scenarios that place a hierarchical value to wetlands (avoid, extra cost, or ignore) can be used to quickly determine cost and acreage impacts.

- NEPA alignments are typically developed using a 'funnel' approach. During the initial screening, the universe of alignments and geographic coverage is considered, which is continually screened down to more specific alignments. To mirror this process, Quantm scenarios require continual adjustment of the outer boundaries in order to focus the alignments toward a specific corridor. As specific corridors are identified, Quantm scenarios are best developed as seeded runs, where a specific route is identified and Quantm provides small adjustments in an attempt to optimize the alignment.

- Residential land use represented the largest constraint (geographically) of the study area in the Quantm NEPA evaluation. Logically, it had the greatest influence on Quantm output in terms of alignment lengths, costs, and volumes of cut and fill. This observation confirms the need for specific existing land use data for Quantm study areas. Creating existing land use layers directly from recent aerial photography provides a quick means to build the data layer.

- Future land use data would provide useful alignment comparisons and could be overlaid as a GIS layer with alignments developed from existing land use scenarios.

6.0 COST/BENEFIT ANALYSIS

This section describes an evaluation of the costs and benefits of using Quantm for transportation planning projects. This evaluation was performed in four steps. First a survey was developed and provided to project team members who were previously involved in projects that utilized the Quantm process and software. The purpose of the survey was to gather information and quantify the magnitude of costs and benefits provided by Quantm.

The second step in this cost/benefit analysis was to compile case studies where Quantm was used to identify those factors that affected the costs and benefits of using Quantm. Where possible, project team members were asked to participate in the user survey to better quantify the costs and benefits of using Quantm.

The third step in this cost/benefit analysis was to compile ranges of estimated costs for the different work phases typically included in transportation planning projects, including the Case Study project. These estimated cost ranges are then combined with the results of the user surveys to provide an indication of the potential magnitude of cost savings provided by the Quantm process.

Finally, the study team worked with the Quantm system through the course of training, Pre-NEPA analysis, and NEPA analysis to get an understanding of the capabilities and work involved in using the software. This understanding was combined with Carter & Burgess' experience with transportation planning projects (particularly the Case Study) and the results of the surveys and case studies to determine where Quantm would either require extra work or provide efficiencies, and where extra costs would be incurred or cost savings could be realized.

6.1 User Survey

The purpose of the user survey was to gather input from project team members who had previously used Quantm on transportation planning projects in the United States. This section describes the methodology that was used to prepare the survey, who received the survey, and the results.

One of the primary objectives of this study was to evaluate the effectiveness of Quantm for NEPA projects. Since regulations exist that govern the analyses that must be performed within a NEPA project, the project team wanted to identify common work phases that are often performed within NEPA projects. These work phases could then be used to quantify how Quantm affects a project in terms of costs and benefits.

The first step in identifying the work phases was to meet with staff within the Carter & Burgess Denver office who frequently perform NEPA analyses. These meetings confirmed that NEPA projects generally follow a fairly well-defined process of work phases. Second, we reviewed the NEPA regulations to identify the analyses that must be performed as part of a NEPA process or document. The work phases that were identified are listed below with a short description.

- *Project Initiation and Continuing Requirements*
  This work phase includes the parts of a project that are supervisory and are performed for the whole project duration. Typical activities include initial project meetings, stakeholder coordination, process management meetings, progress reporting, partnering and general project management activities including managing scope, budget and schedule.

- *Communication and Public Involvement*
  This work phase includes activities for internal (within the project team) and external (with the public) communication, including open houses, small group sessions, mailing lists, newsletters, press releases, technical committees, policy coordination, project reviews and coordinating communication with Federal, State and local agencies.

- *Survey and Mapping*
  This work phase involves location surveys and map compilation, including pre-survey meetings, aerial surveys, field surveys, planimetric and topographic map compilation, GPS surveys, and researching monument records.

- *Conceptual Design*
  This work phase provides conceptual designs for each alternative. Typically, the project team develops preliminary concepts of structures and landscape/ streetscape improvements for alternatives, develops plan and elevation drawings of bridge structures, planting masses, and develops plans illustrating access and development potential of adjacent areas for the alternatives.

- *Alternatives Analysis*
  The purpose of this work phase is to evaluate criteria definitions, develop suitable alternatives, and screen alternatives down to those that satisfy the functional classification and operational requirements of the project. A preliminary screening process is often used on the universe of alternatives to identify a limited number of feasible and significantly different alternatives which will be subject to more detailed evaluation. The No-Action alternative must be carried through the entire evaluation and assessment process.

- *Environmental Data Collection*
  Environmental data collection is usually performed in two phases. The first is cursory and is used to assist in screening alternatives. The second phase, which commences once a set of alternatives has been identified, is much more exhaustive and typically involves field surveys. Datasets that are commonly collected during this work phase include land use, noise, air quality, floodplains, water quality/water resources, wildlife and fisheries, wetlands, threatened or endangered species, pedestrian and bicycle facilities, recreation facilities, economics, social, environmental and related justice impacts to low-income or minority populations, public safety and security, farmlands, hazardous materials, archeological and historic properties, paleontology, visual quality, energy, parklands and wildlife.

- *Cumulative Impacts Analysis*
  This work phase involves the analysis of any direct or indirect effects and cumulative impacts on the natural and man-made environment as a result of action on any of the alternatives.

- *Report Preparation*
  This work phase includes time spent on preparing draft and final versions of the EIS.

- *Engineering Design*
  This work phase consists of design field survey, traffic engineering, hydrology, hydraulic engineering, utility coordination, roadway design and roadside development, transit design, right-of-way research, major rail engineering, station and park-n-ride, design, landscape design, Bus/HOV/BRT design, utility design and system safety design.

- *Data Management*
  This work phase includes activities required to manage the flow of information during the project. This includes the development of tools and applications to assist project teams such as project collaboration websites, resource libraries and producing GIS and MIS data and applications.

- *ROD Preparation*
  This work phase includes all activities that are performed in preparing the record of decision for the project.

- *Construction*
  This work phase includes all activities that are performed to physically construct the project.

A two-part questionnaire was prepared as part of this study. The first part of the questionnaire asked the user to respond to a series of questions about the nature of the project and their feelings about the costs and benefits of using Quantm. In the second part of the questionnaire, users ranked the cost and schedule benefits of using Quantm for each of the work phases described above on a scale from significant decrease (greater than ten percent) to significant increase. Appendix C includes a copy of the questionnaire.

The list of people that were sent surveys was developed by searching the internet for projects that utilized Quantm, Carter & Burgess (project team) knowledge and by getting names of users from Quantm. Carter & Burgess called the targeted respondents prior to sending them the survey to describe the objectives of the project and to ensure their commitment to completing the survey. Table 9 lists the people who were sent surveys.

Table 9: List of People Sent Surveys for Cost/Benefit Analysis

Person	Company	Project Name	Completed Survey?
Michael Sexton Nishant Kukadia	Carter & Burgess	I-69 Corridor – SIU 7 & 8 (Texas)	Yes
Jim Heacock Kay McKinley Steve Connor	TxDOT and URS Corporation	SH 35 Corridor Study (Texas)	Yes
Bryan Copeland	Carter & Burgess	SH 190 Eastern Extension (Texas)	Yes
James Brown Paul Bopp	Transportation Corridor Agencies	Foothills Transportation Corridor-South (California)	No
Trevor Howard	DMJM Harris	Goose Creek Bypass (Idaho)	Yes

Some people decided to e-mail the completed surveys back and others required a project team member to discuss the survey over the phone. The rightmost column in the table above shows whether or not a completed survey was obtained for each person.

As part of the literature review that is discussed in the next section, Carter & Burgess examined published studies about projects that used Quantm for transportation planning. Where possible, we contacted the original project team and asked them to complete a user survey as well. However, in some cases, we could not identify and locate a project team member in time to be included in this report. In those cases, a user survey was completed using the information contained within the published studies. The results of these user surveys are included in the discussion below.

Table 9 summarizes the results of the user surveys. As shown, most users indicated similar results for how Quantm affects time and cost. The users for the I-69 project did not provide feedback on how Quantm affected the costs of their project. The survey completed for the SH-35 Corridor Study did not indicate any work phases where Quantm reduced time or cost. Instead, they indicated that work was slightly more time consuming and costly using Quantm. The survey from the SH-190 project indicated increases in time and cost for four work phases (project initiation and continuing requirements, communication and public involvement, survey and mapping and environmental data collection) and decreases in two work phases (alternatives analysis and report preparation). The survey from the I-69 project was somewhat incomplete but indicated a decrease in time for alternatives analysis. The survey from the Goose Creek Bypass Study indicated significant decreases (greater than ten percent) in time and cost for three work phases (conceptual design, alternatives analysis and environmental data collection) but increases in two work phases (communication and public involvement and data management). The survey for the California High-Speed Rail project indicated significant decreases in two work phases (alternatives analysis and engineering design) but did not respond to how Quantm affects the other work phases. Last, the survey from the Foothills Transportation Corridor South project indicated significant decreases in two work phases (project initiation and continuing requirements and alternatives analysis but did not respond to how Quantm affects the other work phases.

In summary, the user surveys generally indicate that using Quantm on a project requires a slightly higher level of effort to collect and manage data. Cost and time savings are generally indicated in the alternatives analysis and engineering design work phases, although results can vary. One potential explanation for these differences is the wide variety of project study area conditions discovered in the research. For example, projects for study areas that were hilly or mountainous generally showed greater benefits than those projects where the study area was topographically flat.

6.2 Review Other Environmental Planning Studies

Additional projects that used Quantm were reviewed to identify how Quantm was used and what types of costs and benefits were realized. The projects were limited to those within the United States to ensure that the results are relevant to how Quantm might be used within Colorado. The projects were identified by performing internet searches and through Quantm's staff.

Four other environmental planning studies were reviewed. All four studies were performed to comply with NEPA and all had either produced an EIS or are projected to produce an EIS. Three of the projects were new highway alignments and one of the projects was a high-speed rail corridor selection. A complete summary of each of the studies is included in Appendix C.

Based on the four case studies, it appears Quantm produced measurable benefits in not only time and cost savings, but in some intangible areas that might not have been considered originally as part of the overall process. The four studies generally concur on five main points:

1. Quantm produced shorter (distance) alignments than those envisioned by planners and engineers using more conventional methods, meaning they would be less expensive to construct;
2. Quantm alignments had fewer elevation and grade changes;
3. Quantm alignments did a more thorough job of avoiding areas of both environmental and social concern (i.e., recognizing constrained areas);
4. While conventional methods for the designing of only a few alternatives normally took weeks or even months, Quantm produced substantially more alignments – many of which would not have been conceived by the project team - and in only a matter of days, thereby greatly reducing the length of the alternatives evaluation and screening processes; and
5. Quantm alignments were generally more favorable than those produced by planners in that they appeared to the public and cooperating agencies as entirely objective.

While none of these studies mentioned a factoring in of the cost to use Quantm in their analyses (i.e., system utilization costs versus savings benefits revealed in the outputs), Quantm was shown to be beneficial to the user in both time and cost savings areas overall. Additionally, drawbacks of the system were not discussed in the literature cited.

Table 10: User Survey Summary

Alternatives Analysis	▲	▼	▼	▼	▼	▼	▲	◊	-	▼	▼	▼
Environmental Data Collection	▲	▲	◊	▼	-	-	▲	▲	-	▼	-	-
Cumulative Impacts Analysis	◊	◊	◊	-	-	-	◊	◊	-	-	-	-
Report Preparation	▲	▼	◊	◊	-	-	▲	▼	-	◊	-	-
Engineering Design	◊	◊	-	◊	▼	-	◊	◊	-	◊	▼	-
Data Management	▲	◊	◊	▲	-	-	▲	◊	-	▲	-	-
ROD Preparation	-	-	-	-	-	-	-	-	-	-	-	-
Construction	-	-	-	-	-	-	-	-	-	-	-	-

Legend

▲	More than 10% Increase (Significant)
▲	Between 1% and 10% Increase (Slight)
◊	No Change
▼	Between 1% and 10% Decrease (Slight)
▼	More than 10% Decrease (Significant)
-	No Response

Notes

SH35	State Highway 35 Major Corridor Feasibility Study
SH190	Eastern Extension of SH190
I-69	I-69 Corridor: Shreveport to El Dorado
GCB	Goose Creek Bypass
CA HSR	California High Speed Rail
FTC-S	Foothills Transportation Corridor South

6.3 Cost Analysis

Section 6.1 describes the development of ten work phases that are typically performed as part of NEPA studies. In addition, Section 6.1 describes the procedures and results of a survey administered to people who have previously used Quantm on transportation planning projects. As part of this survey, the survey participants were asked to quantify the cost and time effects that Quantm had on each of the ten work phases. Table 10 summarizes the results of the survey.

In order to calculate the overall cost and benefit of using Quantm, it is necessary to understand the size of each work phase relative to the overall project. In other words, how much time and money is spent performing each of the individual work phases compared to the overall project level of effort. This section describes the procedures that were used to quantify the proportions of the levels of effort for each work phase and the results. Section 6.4 uses the results of this analysis to estimate the overall cost and benefit provided by Quantm.

The first step in developing this cost analysis was to collect financial information for the Case Study project and other NEPA projects that have been, or are being performed, by Carter & Burgess. The two other NEPA projects that were included in this analysis are described below:

- **US 285**
  US 285 is a proposed road widening project on US 285 between Foxton Road and Bailey, Colorado. The project is subject to NEPA guidelines and has produced an environmental impact statement (EIS). For the purposes of the Environmental Impact Statement (EIS), the study corridor followed the current US 285 alignment with a data gathering boundary of up to 500 feet in width depending on topography constraints. The universe of alternatives that was proposed contained dozens of interchange concept designs, each of which required significant engineering design to accomplish.

- **Riverside Parkway**
  Riverside Parkway is a proposed transportation improvement that will provide an alternative route of travel through the south side of the city of Grand Junction, Colorado. This project has been identified as a high priority primarily to reduce unacceptable levels of congestion on SH 70B and to improve safety and mobility for all modes of travel passing through and within the Lower Downtown area.

The second step in this cost analysis was to estimate the cost of the ten work phases described in Section 6.1 for each of the three projects. Percentages of the total project cost were then calculated for each work phase. The results of these calculations are summarized in Table 11.

Table 11: Percent Level of Effort for the Phases of a Transportation Planning Project

Work Phase	US 285	Riverside Parkway	Case Study
Project Initiation and Continuing Requirements	11 %	10 %	10 %
Communication and Public Involvement	4 %	18 %	24 %
Survey and Mapping	8 %	7 %	10 %
Conceptual Design	22 %	5 %	7 %
Alternatives Analysis	15 %	12 %	11 %
Environmental Data Collection	10 %	13 %	11 %
Cumulative Impacts Analysis	1 %	2 %	1 %
Report Preparation	12 %	24 %	8 %
Engineering Design	14 %	13 %	14 %
Data Management	3 %	1 %	4 %
ROD Preparation	<1 %	<1 %	<1 %
Construction	NA	NA	NA

While each of the projects listed above were performed at different points in time and had significantly different purposes and needs, the level of effort of each phase of the project was found to be quite similar. As can be seen in Table 11, the proportion of effort between these projects is quite similar for each of the work phases.

There are some notable differences in the proportions, which can be explained by the unique circumstances of each project. For example, US285 required 14 distinct interchange elements, so the conceptual design portion of this effort was substantial. Riverside Parkway project is located on a busy urban arterial passing through downtown Grand Junction. Since it will have a large impact on those businesses and residences located nearby, there is a significant public involvement piece. In conclusion, by estimating which categories above are influenced the most by QUANTM, the proportions can be used to measure the effect of QUANTM will have on the overall project budget.

6.4 Conclusions

The purpose of this section is to identify the costs and benefits of using Quantm on transportation planning projects. Furthermore, this section needs to weigh the costs of using Quantm relative to the benefits of using Quantm so that a determination can be made about whether or not Quantm is cost-effective. The experiences of the project team and the results of the user survey indicate the costs of using Quantm to include the following:

- **Quantm Fee** – Quantm currently charges approximately $10,000 per mile of corridor to use their software on transportation planning projects. This charge includes the training course, data conversion and user support throughout the duration of the project. Some states' departments of transportation (e.g., Texas) have entered into statewide agreements to use Quantm on their projects but our understanding is that the pricing structure remains to be $10,000 per mile.

- **Additional Data Collection and Data Management** – The results of the user survey and the NEPA and Pre-NEPA analyses that were performed as part of this study indicate that a slight increase in cost is required to collect and manage data to be used in the Quantm process.

The current study, along with the literature review and user survey, indicate that a variety of benefits can be realized by using Quantm. These benefits include the following:

- **Reduced Effort for Analyzing Alternatives** – The pre-NEPA and NEPA analyses that were performed as part of this study indicate that Quantm can significantly decrease the time and money spent on developing and evaluating alignments. In addition, many of the user surveys and the literature reviews indicated a significant time and cost saving to identify and evaluate alignments by using Quantm.

- **Reduced Construction Cost Savings –** Quantm claims to provide significant cost savings during construction. This claim was supported by the literature review and the analyses that were performed as part of the NEPA analysis (Section 5). Unfortunately, the projects that were evaluated during the user survey had not yet proceeded to the point of evaluating construction costs and therefore did not provide an indication of Quantm's impact on construction costs.

- **More Thorough Identification of Alignments** – As discussed in Sections 4 and 5, Quantm provides a quick way to evaluate large numbers of possible alignments for a variety of constraints, both physical and engineering. The end result is that Quantm can look at many factors for a potential alignment much more thoroughly than using the traditional approach. This benefit is also supported by the results of the literature survey.

To perform a true cost/benefit analysis for the Quantm approach, it is necessary to estimate the magnitude of the costs versus the magnitude of the benefits. Since Quantm charges $10,000 per mile of corridor, it is simple to estimate the cost of the Quantm fee. For the purposes of this study, the total Quantm fee is $250,000 since the Case Study project is approximately 25 miles in length. In addition, project staff must be trained on the software and spend some time learning how to work with Quantm effectively. We estimate the additional training and 'learning curve' costs to be in the range of 8 man-weeks (four people for one week of training and about one more week of gaining proficiency in use of the system). Based on a rough cost of $100/hour for the personnel on the staff, we estimate the learning expense to be about $32,000. If we assume that the Case Study project would have incurred an additional five percent increase in data collection and management (as indicated by the user surveys) above the four percent of the total project budget (as indicated by the cost analysis), the total additional cost for data collection and management on the Case Study project would be $26,000 ($13 Million total project cost * 4 % for data management * 5 % increase). Therefore, the total estimated cost for using Quantm on the Case Study project is $308,000.

The magnitude of the benefit provided by Quantm in the alternatives analysis portion of the EIS process can be calculated by multiplying the total project cost by the percentage for analyzing alternatives (to get the amount that was spent on developing and analyzing alignments) and multiplying that by the amount saved by using Quantm (from the user surveys). This calculation results in a value of $234,000 ($13 Million total project cost * 15 % for analyzing alternatives [alternatives analysis plus one-half of the engineering design] * 10 % cost savings). Subtracting $234,000 in savings from $308,000 in costs results in a figure of about $72,000 for integrating Quantm into the Case Study project.

Compared to the cost of using Quantm on the project, the potential construction cost savings is very large, given that the estimated construction cost for those elements that can be modeled in Quantm for the Case Study is about $400 million. Although construction cost savings cannot be accurately calculated for the Case Study project, Quantm provided optimized routes that calculated potential savings in the range of 6% - 29% for Vertical Optimizations to over 40% for other Refinement Optimizations if/where some horizontal movement is possible (Section 5.5.2.2). Because every 1% savings in construction costs represents on the order of $4 million, the potential benefit in reduced construction costs greatly outweighs the net investment in the system.

Last, it is difficult to quantify the magnitude of the benefit provided by a more thorough analysis of alternatives. Since the construction cost benefits greatly outweigh the costs for using Quantm, any potential benefit provided by a more thorough analysis of alternatives is minor in comparison and won’t be quantified.

In summary, this cost/benefit analysis indicates that when construction costs are taken into consideration, the benefits of using Quantm can greatly outweigh the costs of the software and preparing the data. Furthermore, we believe that this outcome is probably typical of most projects that are similar in nature to the Case Study project. However, we also believe that Quantm would not provide overwhelming benefits for all projects. Section 7 discusses factors that should be considering when evaluating whether or not to use Quantm.

7.0 FINDINGS/OBSERVATIONS

As a part of the overall project scope (Section 2.0), a number of questions were posed for the study to answer. The questions, and the answers resulting from the study, follow:

Question: Can the Quantm software provide a significant benefit when used in planning transportation improvements in Colorado?

Development of transportation alternatives is a complex public and political process. Quantm provides a unique and powerful tool that can support this process, but it doesn't replace any of the activities of the experts involved in the process. Our finding is that the successful application of Quantm on a project would directly involve GIS experts, environmental planners, and roadway engineers.

Based on our study, Quantm can provide significant benefits to projects that have at least one of the following characteristics:

- An opportunity to optimize cut/fill to save construction costs
- An opportunity to develop new alignments that do not strictly follow an existing route

For projects that meet at least one of the above two criteria, the following criteria are additional indicators that Quantm is well-suited for the project:

- Significant portions of the project include rolling or hilly terrain
- Significant portions of the project may require new roadway alignments or major realignment
- Significant portions of the project are in non-urban areas
- There is a need to investigate all realistic alternative alignments, including new routes
- A project goal is to reduce construction costs by optimizing the vertical and/or horizontal alignment
- The project alignment will be affected by complex environmental and/or social constraints

In general, the following project characteristics are indicators that a project may not benefit from Quantm:

- Projects that are upgrades or repairs to existing roadways (i.e. little change to the vertical or horizontal alignment)
- Projects that are highly constrained in the vertical by intersections and in the horizontal by right-of-way availability
- Projects that are short in length (< 2 miles)
- Projects that are entirely urban
- Projects that are located in relatively flat terrain

Highly urbanized environments present a challenge to the Quantm user in the alternatives development stage of the EIS process, due to the fact that Quantm's algorithms don't have a direct way to favor existing roadways. However, users have a number of options if they wish to specifically include existing roadways in the development of alignments, including:

1. The GIS data can be customized by buffering roadways and "cutting them out" of avoidance areas, so that alignments that try to pass through avoidance areas are directed along the roadway

2. Sections of alignments can be fixed so that they follow existing roadways, while other sections that need to traverse the terrain can be submitted to Quantm for processing

3. Existing road centerlines can be used as a 'seed' for a Quantm optimization run

4. Entire routes can be digitized into Quantm and either optimized inside a narrow corridor or optimized in the vertical direction only

Question: When in the process should the software be applied to provide maximum benefit?

Because the Quantm system works functions within the framework of the NEPA process, and because the cost of the system is on a per-project basis, the best time to apply the software is early in a project, prior to the development of alternative routes. However, the literature includes projects in which Quantm was brought into a project once the NEPA process was well underway and used with good results. Also, because of the optimization capabilities of the software, we believe that Quantm can be used successfully in the design phase of a project that is in rough or rolling terrain.

One of the questions raised during this study was whether Quantm can be used at the early transportation planning stages on a statewide or regional basis, such as during preparation of Statewide Transportation Improvement Plans. The project team believes that the Quantm system could be very useful in such planning exercises. This is due to its ability to quickly generate routes, especially trends of alternatives across a given study area, that meet specified design criteria and take into account any known constraints at that time. However, based on the Quantm pricing structure, the cost of the application is based on the project length ($10,000 per mile), rather than for general system-wide transportation planning. Therefore, Quantm would generally be cost-prohibitive as a tool for system planning in a large geographic area and would therefore require a different contract and pricing structure for such statewide or regional applications.

Question: How are transportation improvement alignments developed and evaluated using Quantm?

The consideration and testing of different scenarios is often a time consuming step in the NEPA alignment development process. Quantm provides a tool to quickly test different scenarios by varying assumptions and comparing results, often on a next-day basis. For example, scenarios that place a hierarchical value to wetlands (avoid, extra cost, or ignore) can quickly determine cost and acreage impacts.

Typical NEPA alignment development processes use a funnel approach to alignments screening. During the initial screening, the universe of alignments and geographic coverage is considered, which is continually screened down to a more and more specific set of alignments. Quantm mirrors the development of the "universe of alternatives," through the use of unseeded scenario runs, where the goal is to consider the broad geographic range of possible alignments. The later focus on specific alignments is mirrored by the use of seeded optimization runs, where the focus of the analysis is on one or more specific corridors.

Question: What are the critical data needs for using Quantm?

Overall, the study team found that a large volume of highly-developed data is not necessary at the beginning of a project that incorporates the Quantm process. The nature of the NEPA process is to move from a large number of possible alternatives to a small number of alternatives through a process of elimination. At the beginning of the NEPA process, Quantm can be best used to develop a broad range of possible alignments when the system has fewer constraints (particularly fewer avoidance areas). The study team has found that the Pre-NEPA data layers that are key to the successful use of Quantm at the beginning of a project are:

1. Digital Elevation Model: The DEM is the basis of the function of Quantm, and the resolution, accuracy, and currency of the elevation model directly affect the quality of the results. Also, cut and fill volume estimates are a substantial overall cost factor and are greatly influenced by the resolution of the digital terrain model. Higher resolution terrain models will yield more accurate volume estimates, however lower resolution models are sufficient during the early stages of analysis (especially pre-NEPA) to identify the opportunities or trends of alternatives.

2. Engineering Parameters: A geometric description of the facilities to be evaluated is critical to the system. As with other data used in the system, the data can be incrementally improved through the course of the project.

3. Aerial Photography: A current aerial photograph or satellite image of the project area, although not essential to the Quantm process, is extremely helpful in identifying and confirming locations of linear features and special zones, and as a visual reference.

4. Base map: Current and accurate road centerlines, railroads, streams, and water bodies are important for reference and for creating linear features.

5. "Absolute" or "Hard" Avoidance Areas: At the beginning of an EIS process, there may be a number of areas that will definitely be avoided by the project either because they are outside of the project study area or because of basic project assumptions (e.g. the project will not pass through Rocky Flats). A layer of these avoidance areas is the best first set of constraints when creating the "universe of alternatives" for a given project.

6. Land Use: In a general sense, the process of creating special zones in Quantm is a process of creating a land use map. A generalized land use layer, compiled from a

number of different sources (zoning or land use, environmental, hydrologic), assists the user to identify "absolute avoid" zones early in the process and evaluate the reasonableness of the alignments. It also allows the early comparison of alignments by defining additional cost areas. Without understanding land use, alignments have little comparative factors other than cut and fill volumes and costs.

Data layers developed during the NEPA process are needed to refine alignments and to compare alignments in terms of cost and environmental and social impact. However, the initial development of alignments to be investigated can be performed with Pre-NEPA data as described above. As the project progresses, incremental improvements to engineering parameters and GIS data can be reflected in the Quantm system.

Question: In terms of cost, how does the Quantm process compare to existing EIS processes?

We estimated that it would have cost about $308,000 to implement Quantm on the Case Study project and that it would have provided about $234,000 in efficiencies to the project (for a net cost of $74,000), not including any savings that could be realized during construction. Although construction cost savings cannot be accurately calculated for the Case Study project, Quantm provided optimized routes that calculated potential savings in the range of 6% to over 40% (Section 5.5.2.2). Because every 1% savings in construction costs represents on the order of $4 million, the potential benefit in reduced construction costs greatly outweighs the net investment in the system. Therefore, our analysis shows that Quantm is very cost effective when applied to projects of a similar nature as the Case Study.

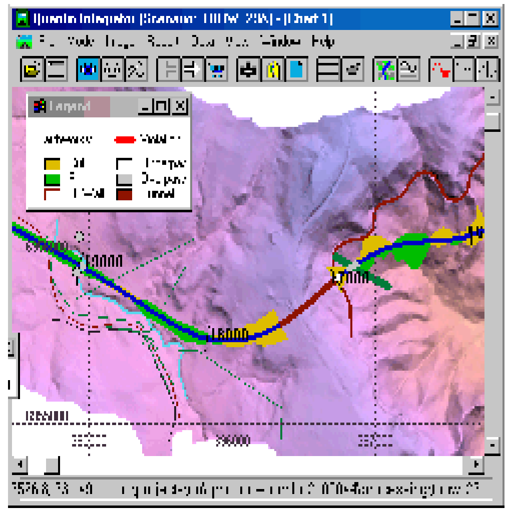
As part of the cost/benefit analysis (Section 6), we conducted a literature review of other studies that have used Quantm. These other studies also indicate that Quantm is generally cost effective for planning projects and that it reduces estimated construction costs.

Question: How does the Quantm process address other modal alternatives?

Often transportation improvements involve multi-modal alignments. Each mode has specific needs and must run independently and concurrently with other modes. Quantm also does not consider dual modes of transportation concurrently, but rather one set of geometric parameters at a time. Therefore, rail and roadway alignments must be analyzed separately. However, Quantm does enable dual modes to be iteratively compared based on the most restrictive geometries, for example comparing the additional costs to run a road alignment in a corridor optimized for rail geometry.

Appendix A:
Quantm Overview (Provided by Quantm, Ltd.)

The Quantm system is a unique route optimization technology and methodology (patent pending) supported by a team that incorporates road and rail engineers, Geographical Information System (GIS) technicians, transport researchers, mathematicians and system developers.



It uses an advanced IT infrastructure, linked to the Internet, that enables project planners to take advantage of Quantm's unique technology from their desktop PC (using Quantm Integrator software) without the financial burden that would be associated with the cost of the IT platform required to run the optimization engine (Quantm Pathfinder). It also allows Quantm's Technical Support Engineers to monitor initial runs to ensure that the planners are maximizing the benefits available from the system, and to provide ongoing support.

The application of the Quantm system is described below. To request a copy of the Quantm CD and 12 minute video demonstration of how the system is applied, please email Quantm

The Quantm system is applied to each project in 8 stages:

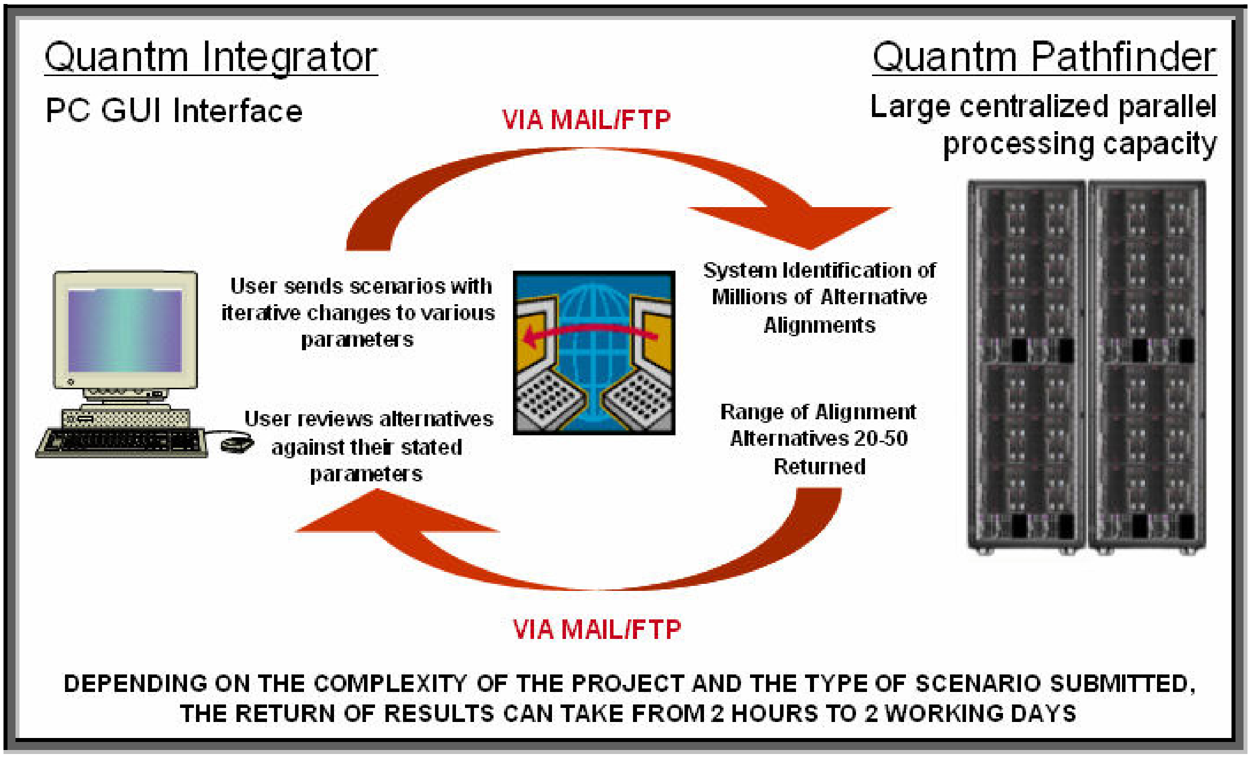
Stage 1: Data conversion

At the start of each project, the client sends digital terrain data to Quantm for conversion into a Quantm Digital Elevation Model (DEM) by Quantm's technical team. Other digital data, such as existing linear features from CAD systems or geology or constraint boundaries from GIS systems can also be converted into the Quantm format prior to the commencement of training. The terrain and other data inputs can be translated from a wide range of formats, including DXF and DGN (files, 3D triangles and XYZ points), ASCII, ESRI (GIS shapefiles and Grids), Terramodel, Genio Moss file and others.

Quantm provides planners with the option to commence pre-feasibility and corridor scoping studies using coarse data initially, and then move to more detailed/accurate data as it becomes available.

Stage 2: Creating and testing a project database

The Quantm team creates a project database around the DEM. This is then loaded into Quantm Integrator (front-end software) and also installed on Quantm Pathfinder (the optimization engine housed at Quantm). Using data provided by the client, or historic data from past projects, the Quantm team tests the project database prior to the commencement of training.



Stage 3: Installing Quantm and the project database

At commencement of the Quantm training, Quantm Integrator and the project database is loaded onto the planner's PC (or anyone who will be involved in data input or constraint and alignment review using the Quantm system). The version of Integrator provided is already encrypted to the project database, providing a high level of security for data transmitted through the internet – it can only be read by the version of Integrator that includes the project specific decryption code.

Stage 4: Quantm training

Quantm training is a comprehensive 5-day program that has been developed to provide project teams with the skills required to fully utilize the capabilities of the system. It is delivered by Client Service Engineers who have extensive planning experience with the Quantm system.

The training is completely hands-on (with a maximum attendance of 4 users per Client Service Engineer) and uses a combination of 'training data' and actual project data. This means that by the end of the training program, the users will already have input data and reviewed alignments for their own project. On some small projects (2-4km) where all of the data had already been gathered prior to the commencement of the Quantm application, the route selection process was actually completed during the training program.

Stage 5: Data input

The Quantm system has been developed for ease of use by planners and project members who are used to operating GIS and CAD software. Data is input, or amended, using drop down menus and dialogue boxes, including engineering parameters, geology, constraint zones (avoid or special treatment), existing features (with crossing rules), structures and costs (see Data Input for more detail).

On completion of data input, the Scenario (a unique data set) is saved and submitted to Quantm Pathfinder (via the Internet) for optimization.

Stage 6: Corridor and alignment review

Quantm Pathfinder costs and considers literally millions of route options that meet the client-defined constraints before delivering a range (20 - 50) of 'best option' alignments to the project team for review, using Quantm Integrator.

Alignments can be viewed in Plan or Profile and the Quantm system is designed to allow the planner to view cross sections, and review and compare the earthworks footprint and acreage of different options, with cut and fill clearly displayed in different colours. Each alignment has an associated summary chart that defines the earthwork volumes and costs for cut, fill, borrow, dump and haul, as well as length and cost of retaining walls, culverts, bridges and tunnels. See Reviewing Alignments for more detail.

Stage 7: Re-submitting for optimization

Route planning is a complex iterative process that will need to consider a range of alternatives and respond to environmental and community issues. The speed of the Quantm system allows the planner to quickly refine identified alignments, reoptimize to undertake comprehensive sensitivity analysis or consider new constraints arising from the EIS or public consultation process.

Once the initial scenario has been created, new scenarios can be defined in minutes and submitted for optimization. Quantm Pathfinder will return a range of ‘best option’ alignments to the planner for review within two working days but typically overnight.

Stage 8: Exporting to third party software

The centerline of the selected alignment, or shape files of the earthworks footprint can be simply exported into standard CAD packages, such as InRoads, GeoPak and others for detailed design or to utilize 3D visualization capabilities for virtual 'fly-over' presentations, and line-of-sight analysis.

Alignments can also be exported (in an iterative manner) into travel time, user cost, energy/fuel consumption or whole-of-project costing models to integrate operating issues into the route selection process.

Appendix B:
Case Study Description: Northwest Corridor Project

In order to evaluate the Quantm software application using a real-world project, CDOT chose the Northwest Corridor (NWC) project as a case study: an on-going NEPA project in the Denver Metropolitan Area. For this project, the Federal Highway Administration (FHWA), in cooperation with CDOT, is preparing an environmental impact statement (EIS) in accordance with NEPA for an improved connection between the western terminus of the Northwest Parkway in Broomfield County and the SH 58, I-70, or C-470 freeway systems to the south in Jefferson County (Figure B-1). This connection is considered necessary to address the need for system linkage, to provide for existing and projected transportation demand, to improve safety, and to enhance modal interrelationships, with the Northwest Quadrant of the Denver Metropolitan Area.

General alternatives under consideration include:

1. Taking No Action
2. Construction of a New Highway Alignment
3. Improvement of the Existing Highway Network
4. Improvement of the Existing Arterial System
5. Transit Options
6. Expansions to the Existing Bus System

NWC PURPOSE

- ✓ *Improve the functionality and capacity of the regional and local transportation system*

NWC NEEDS

- ✓ *Corridor Capacity – Adequately accommodate existing and projected demand for the movement of people, goods, and information*

- ✓ *Travel Reliability – Reduce the increasing travel delays for interregional and regional trips*

- ✓ *System Connectivity/Accessibility – Provide access between local communities, developing urban centers and statewide locations in response to continuing growth*

- ✓ *Opportunities for Intermodal Connections – Enhance mode choice opportunities to improve mobility*

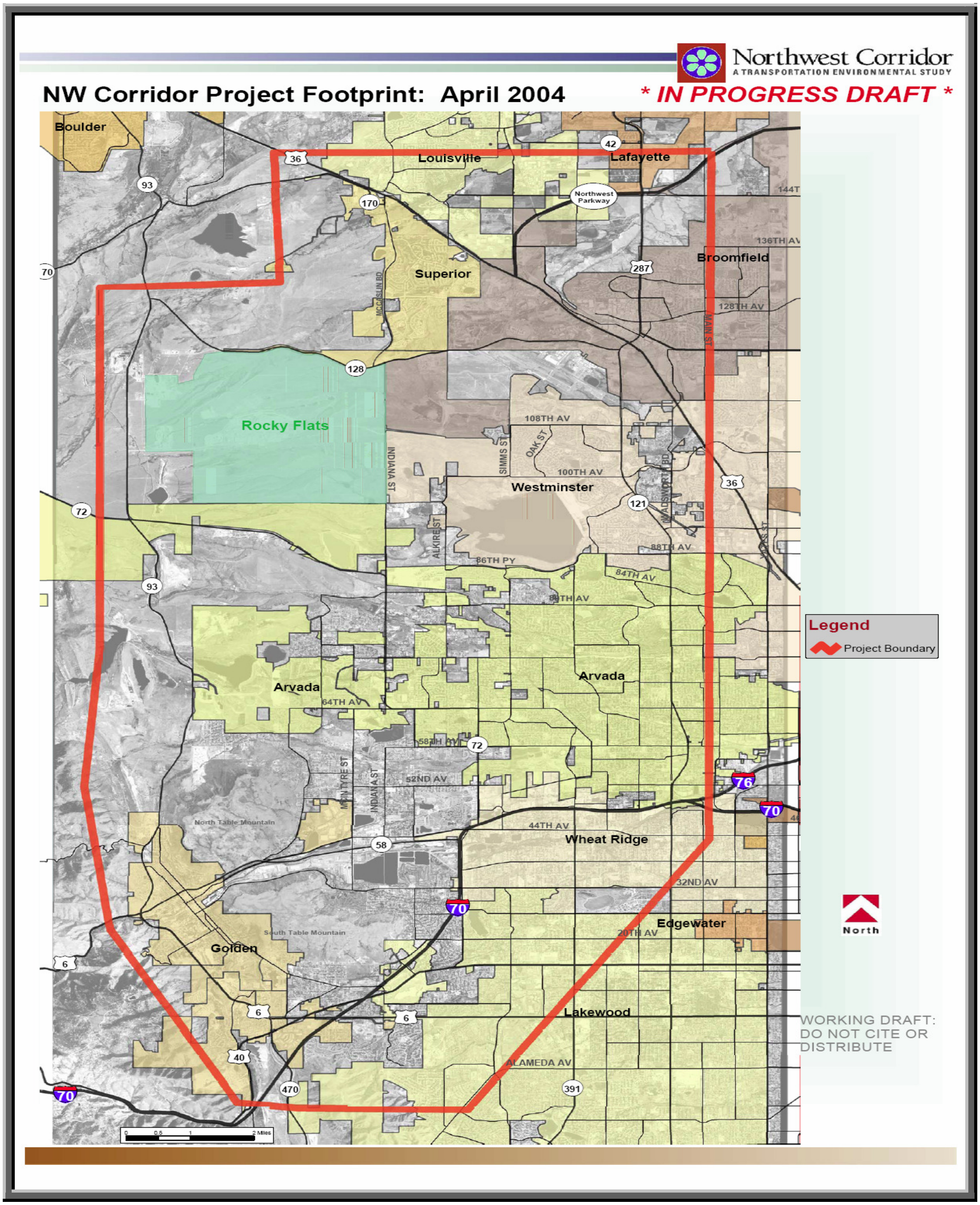


Figure B-1: Working Draft NWC Study Location Map
Source: www.dot.state.co.us/NorthwestCorridorEIS

B.1 NWC ALTERNATIVES DEVELOPMENT AND EVALUATION

The alternatives development process proposed for the NWC project includes a 3-tier system of identification, comparison and screening, and elimination that began in late 2003 and is currently on-going (Figure B-2). Multi-modal transportation improvement alternatives are being developed and evaluated through the EIS screening process, where the "universe of alternatives" are being refined into a preferred set of alternatives that can be compared to the No Action alternative (Figure B-3). At each level of evaluation in the EIS process, more is learned about the project needs and alternatives through transportation planning and engineering, through environmental analysis, and through the public and cooperating-agency process.

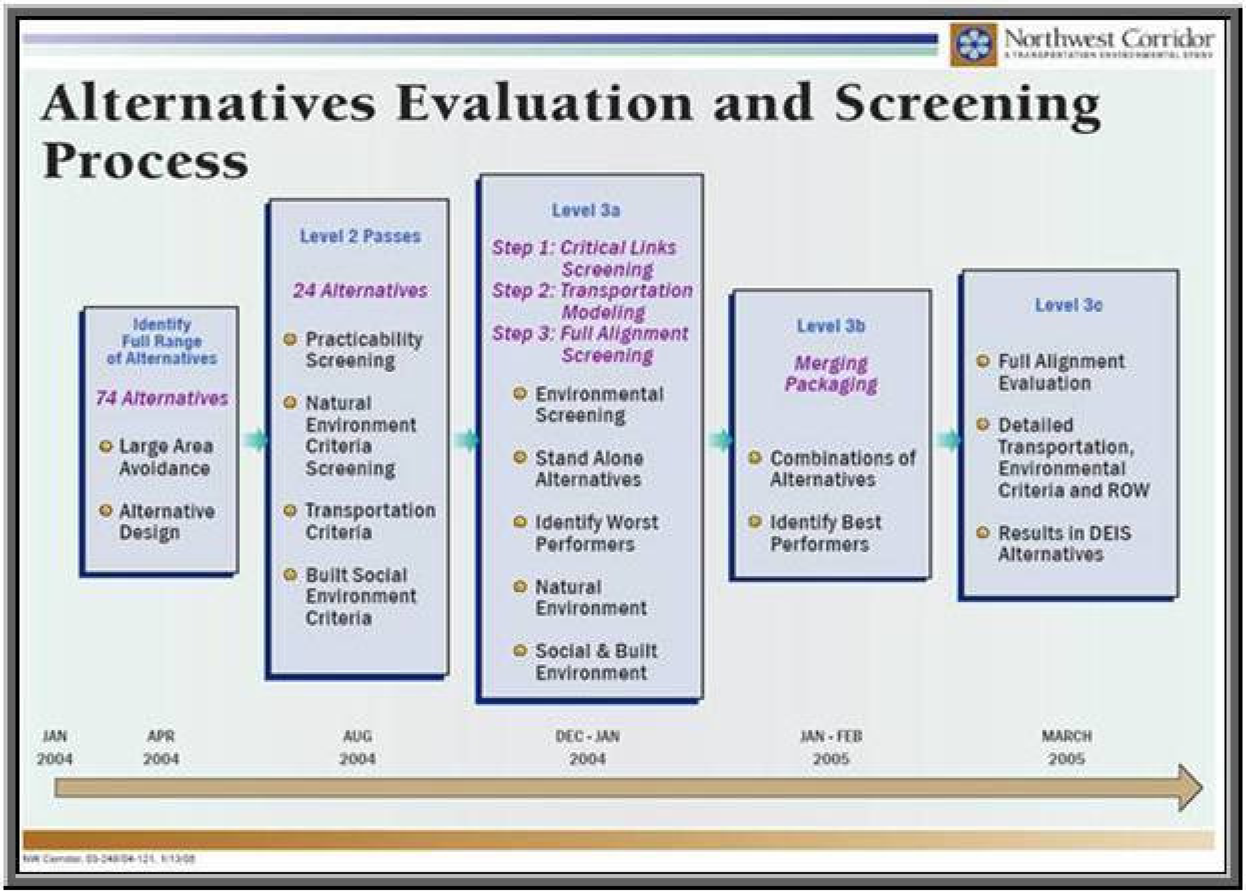


Figure B-2: NWC Alternatives Evaluation and Screening Process
Source: www.dot.state.co.us/NorthwestCorridorEIS

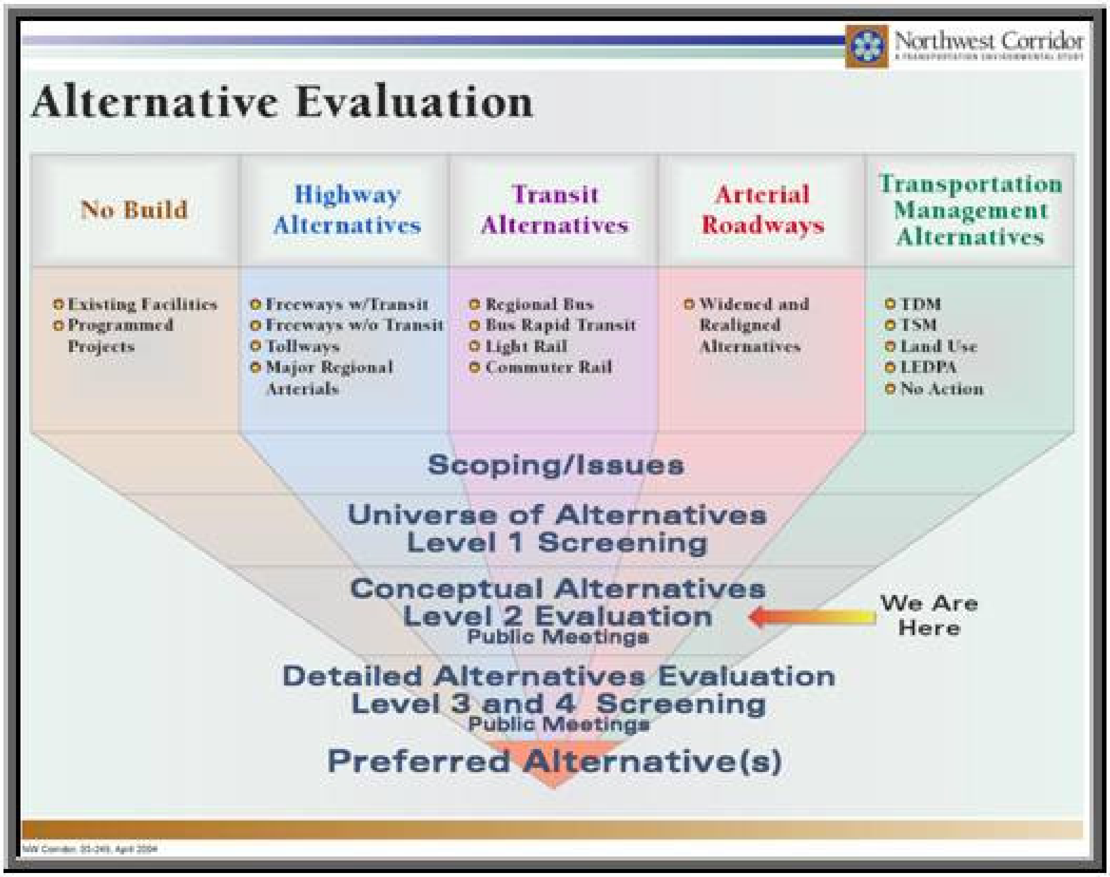


Figure B-3: NWC Range of Alternatives
Source: www.dot.state.co.us/NorthwestCorridorEIS

B.2 NWC LEVEL 1 GIS DATA AVAILABLE ON PUBLIC DOMAIN

GIS data available to the NWC project for use in the Level 1 alternatives screening from public domain sources are summarized in Figure B-4.

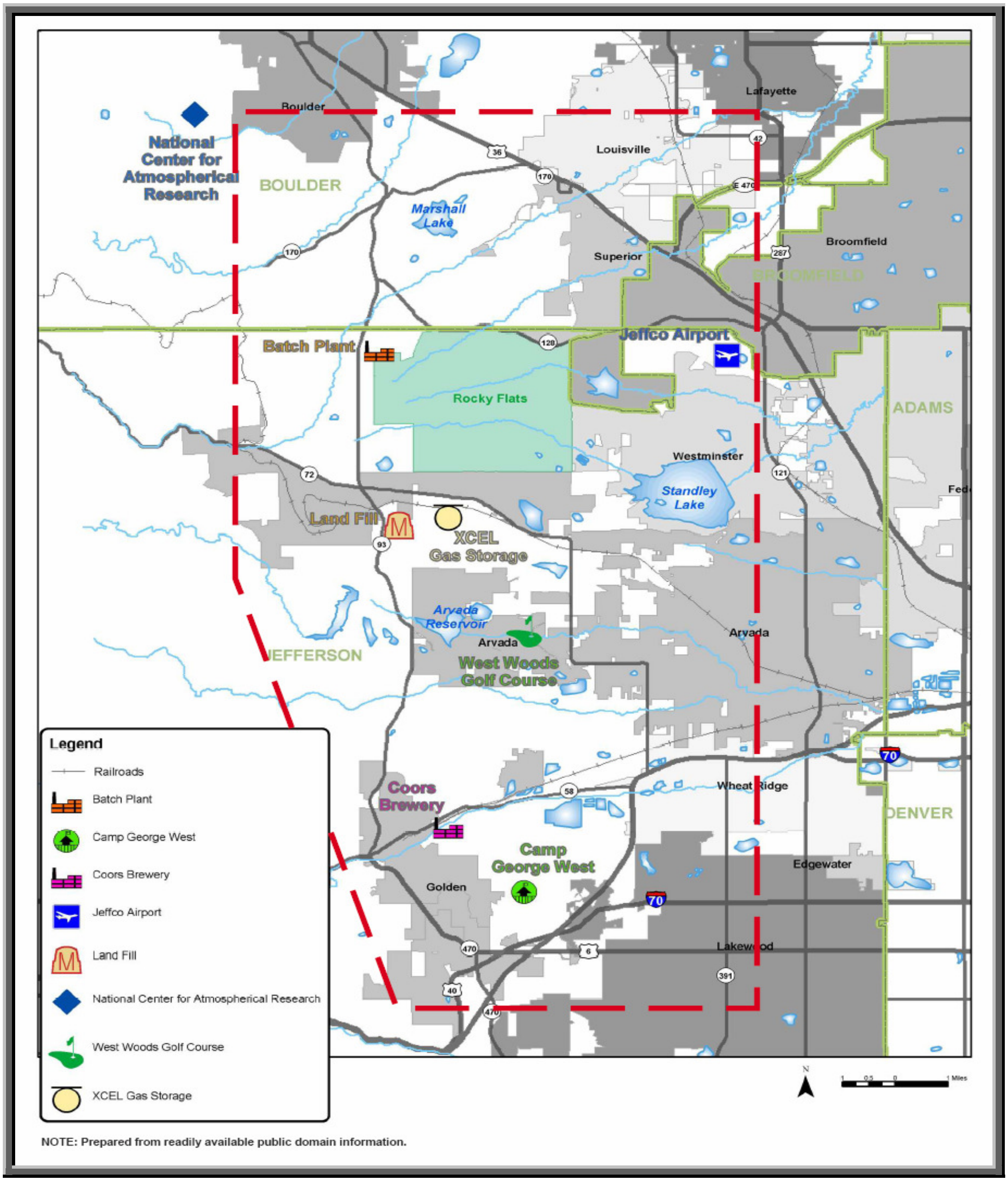


Figure B-4: NWC GIS Data Available on Public Domain

Source: www.dot.state.co.us/NorthwestCorridorEIS

B.3 NWC ALTERNATIVES SCREENING PROCESS

Initially, the full range of more than 74 multi-modal transportation improvement alternatives were developed by transportation planners for the Level 1 analysis. These alternatives were ultimately screened down to 24 alternatives for Level 2 analysis by eliminating those were technically and fiscally infeasible or had obvious impacts to eight regionally-sensitive resources. Criteria for the regionally-sensitive resources were identified with stakeholder involvement and include view sheds, water bodies, large residential areas, hazardous materials sites, and land use compatibility, among others. Figure B-5 depicts the Level 1 screening scenario for eliminating alternatives from Level 2 consideration.

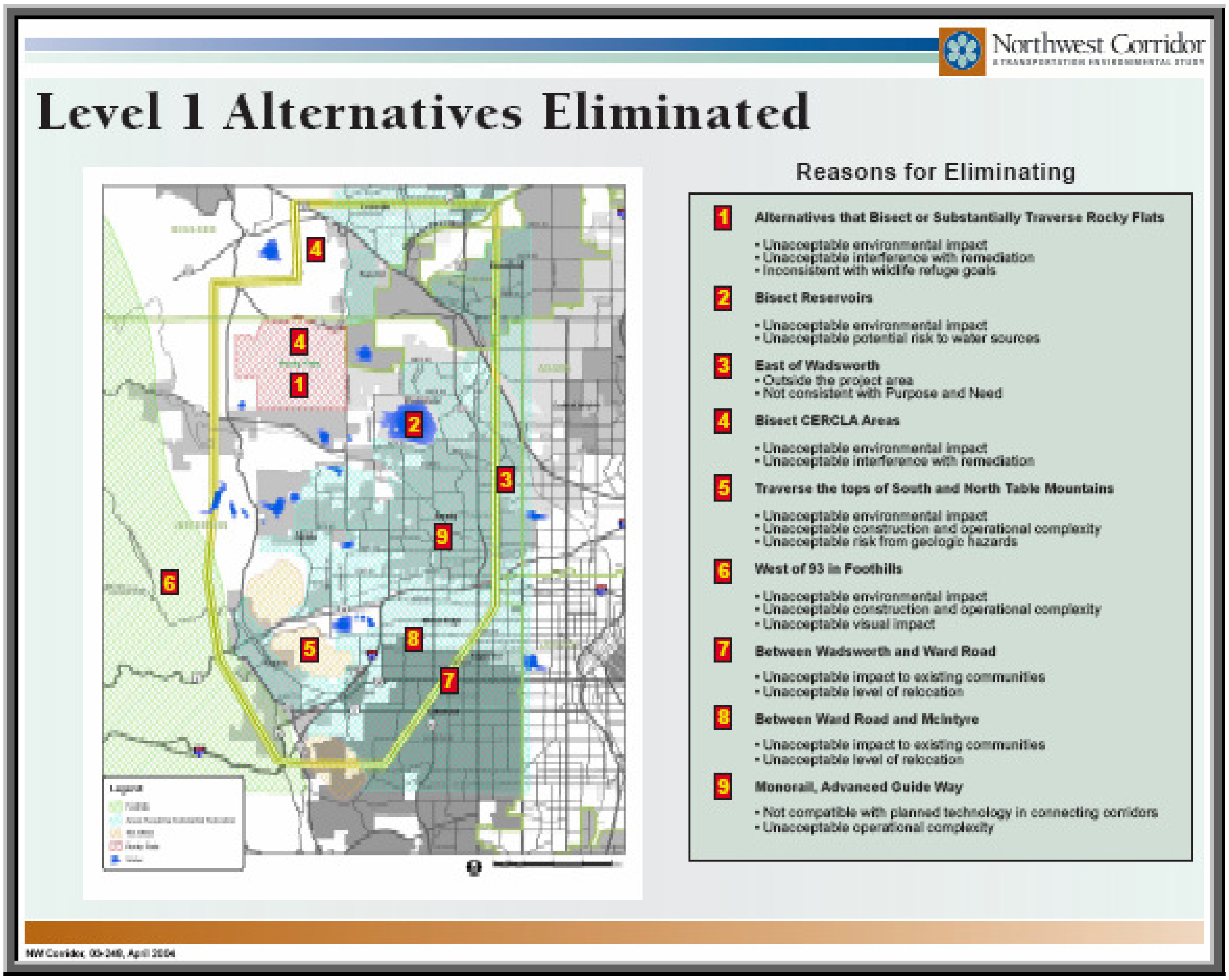


Figure B-5: NWC Level 1 Screening Scenario
Source: www.dot.state.co.us/NorthwestCorridorEIS

B.4 NWC LEVEL 1 SCREENING RESULTS

In order to provide a general idea of the types of alternative under investigation in the NWC EIS, examples of the routes followed by the “universe of alternatives” are depicted in Figure B-6. It should be noted that the majority of alternatives developed and evaluated for the NWC generally follow existing roadway corridors.

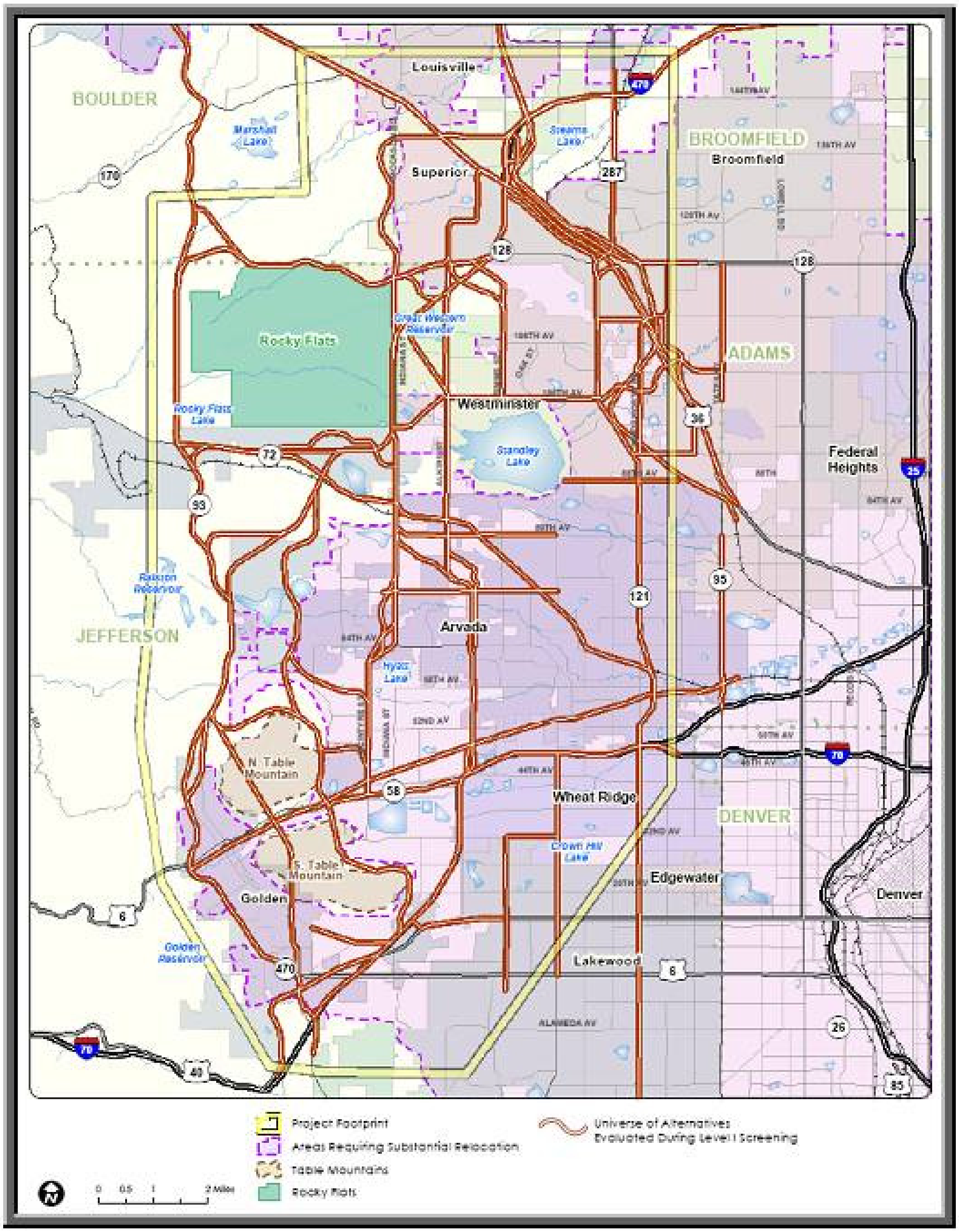


Figure B-6: Routes covered by the NWC “Universe of Alternatives”
Source: NWC Project Team

Appendix C:
Quantm User Questionnaire

Quantm Experience Questionnaire

User:
Title:
Agency:
Date:

1) Please describe the project(s) that included Quantm:
   - highway or rail
   - length of corridor
   - length of project (timeframe)
   - urban or rural
   - mostly new corridor or mostly existing corridor
   - flat terrain or lots of relief

2) How was Quantm used (i.e., in what stage)?
   - early planning
   - alternatives development
   - preliminary design
   - full EIS process

3) Was your overall experience with Quantm positive or negative?
   - Where was it positive?
   - What benefits did it provide?

   - Where was it negative?
   - Did it cause any problems?

   - What about Quantm support?

4) What disciplines were involved in its utilization (planners, engineers, etc.)?

5) Did you use Quantm for public and agency involvement, or just internally?

   - Did the public, agencies understand what Quantm was for?

6) Under what conditions would you use Quantm again?

7) Any tips or tricks you would share?

8) Was a Quantm-generated alignment the recommended alternative?

Run through the Excel matrix/questionnaire on Quantm's effects on project timeline and costs.

Key questions related to the matrix:

- Overall, did Quantm save the project **time**?
- Overall, did Quantm save the project **money**?
- Was it worth it?
- Did it speed up your process?
- In any case, did Quantm *cost* you any time and/or money?

Thank you very much for your time!

User: User Unknown **Title: Unknown**
Agencies: State DOT **Date: April 2005**

	How Quantm Affects Time					How Quantm Affects Cost						
Activity	**>10% Decrease**	**1-10% Decrease**	**No Change**	**1-10% Increase**	**>10% Increase**	**>10% Decrease**	**1-10% Decrease**	**No Change**	**1-10% Increase**	**>10% Increase**	**Description**	**Your Comments**
Project Initiation and Continuing Requirements											Initial project meeting, project schedule, progress reports, develop design criteria, progress meetings	
Communication and Public Involvement											Contact database, general public meetings (prepare, attend), ADA compliance, communication aids	
Survey and Mapping											Pre-survey meetings, collect primary data/area of potential direct effect, aerial survey, field surveys, right of entry, planimetric mapping, topography, GPS surveys	
Conceptual Design											Cursory collection of environmental data	
Alternatives Analysis											Evaluation criteria definitions, develop alternatives, intial screening, cost estimate and financial analysis, additional alternatives, final alternatives	
Environmental Data Collection											Exhaustive data collection	
Cumulative Impacts Analysis											Direct and indirect effects, cumulative impacts.	
Report Preparation											Report preparation, draft, review and comment	
Engineering Design											Design field survey, traffic engineering, hydrology, hydraulic engineering, utility coordination, roadway design and roadside development, transit design, ROW research	
Data Management											Management systems, applications, tools, PI & other use	
ROD Preparation											Report preparation, draft, review and comment	
Construction											Construct selected alternative	
					✓					✓		

Appendix D:
Literature Review

I-69 Corridor – Shreveport to El Dorado

This project is an EIS for a 70-mile divided (four-lane) interstate highway between El Dorado, Arkansas and Shreveport, Louisiana. The project will be part of the National I-69 Corridor and was also identified as a Section of Independent Utility (SIU) No. 14. An EIS was prepared for the project by URS Corporation.

The project team noted that Quantm's data input requirements were more rigid and required more preparation for use than the traditional approach. It was also noted that Quantm's effectiveness was only as good as the quality and comprehensiveness of the data inputs.

With regard to labor savings, the URS study revealed that while additional time was required for coordinating and preparing the data inputs for the model, these efforts would also have been part of the scope of the traditional approach. In fact, the study noted their Quantm evaluation produced cut and fill quantities, an optimized horizontal and vertical alignment, and cost estimates in a fraction of the time that would be spent by the project team. For example, the project team originally scheduled three months to identify a preferred corridor and then an additional three to four months to produce accurate line and grade details. If the public involvement activities were removed from this work, the total time estimated to select a preferred corridor and develop line and grade details was four months. By utilizing Quantm for corridor evaluation, the project team realized significant time savings, noting that "the development of results took only a few days."

The project team also felt that a substantial cost savings benefit was also realized as a result of utilizing Quantm. To prove this point, the project team developed a list of theoretical cost assumptions and concluded that Quantm could have produced a savings of $371,000 (16 percent) if the system had been used for corridor selection and line and grade activities since project inception. Specific cost savings elements cited in the study include:

- Reducing costs for developing vertical and horizontal profiles;
- Reducing costs for developing quantities estimates;
- Elimination of the need to evaluate 2-mile-wide corridor alignments prior to evaluating 300-foot-wide highway alignments; and
- Reducing administration and coordination time and costs.

The project team also felt that using Quantm to develop the alignment would save approximately five to ten percent of construction costs versus the cost to construct an alignment developed using the traditional approach.

California High-Speed Train Program PEIR/EIS

As part of the PEIR/EIS process for evaluating a potential high-speed rail corridor connecting northern to southern California, the state's High-Speed Rail Authority utilized the Quantm system for the first time in the U.S. as part of its screening evaluation of alignment options. According to the report, the alignments considered in the initial screening process were highly constrained by land use issues and/or associated environmental limitations. Two favorably-located mountain crossings within the corridor encountered a particularly large number of obstacles, due to vast differences in both horizontal and vertical alignments, as well as grade options. Due to the potential for a wide range of impacts within the mountain passes, the Authority embarked upon an alignment optimization and refinement effort to further clarify the screening decisions using the Quantm system. In fact, the system evaluated and provided cost estimates for approximately 12 million horizontal and vertical alignment options with each run over a three-week period, thereby producing the best range of lowest-cost alignments within the various constraints and parameters.

In this case, Quantm was utilized to compare to two alignments previously evaluated in 1999. The first was the Diablo Mountain Crossing corridor (said to be advantageous in terms of travel time but with very challenging and remote terrain), which was previously assumed to be constructed as a 31-mile tunnel alignment through the mountain crossing, albeit difficult and costly to construct. As the report tells it,

> "Using the Quantm system the study team was able to identify an alignment at a maximum grade of 3.5% that minimizes tunneling to a total of 11.3 miles and limits single tunnel length to just over 5 miles – reducing the associated construction cost by at least $2 billion."

For the SR 152/Pacheco Pass corridor, Quantm identified an alignment and profile option that would result in required tunneling of only 5 miles, compared to an 18-mile tunnel alignment option originally proposed in the 1999 "Corridor Evaluation Study."

The state of California possesses another unique geologic constraint in that there are fault lines and seismic avoidance areas that also must be considered when evaluating highway and railroad corridor alternatives. The report notes that alignment options using 2.5% maximum grades are unable to cross major faults at-grade and require a continuous tunnel segment of at least 16 miles.

With Quantm, the alignments were increased to a maximum grade requirement of 3.5%, in order to provide more flexibility in avoiding major faults at-grade than previously thought. In the case of the I-5/Grapevine corridor within the Tehachapi Mountain Crossing, Quantm was utilized to refine alignment options that would require only 18 miles of tunneling, compared to 28-35 miles of tunneling required for alignments proposed in the 1999 study.

The report concludes by stating the Quantm system was invaluable for producing the most optimal alignment options in terms of minimizing infrastructure requirements for both of the mountain crossings studied. It notes,

> "The Authority would not have had the time or resources to identify and evaluate the broad range of potential options/variations (literally millions) through these mountain crossings and achieve this level of confidence through any other means."

While no potential cost savings tables were included in the report, it recognized that using Quantm would deliver substantial savings by determining the optimal alignment in a very short timeframe.

Foothills Transportation Corridor-South (FTC-S)

The Foothills Transportation Corridor-South (FTC-S) project's objective is to build and operate a 16-mile toll road from Oso Parkway in Rancho Santa Margarita to the I-5 Connector at the Orange-San Diego County border in Southern California. It is to include two general-purpose lanes and one future high-occupancy vehicle (HOV) lane in each direction. In the beginning, 19 alignment alternatives were developed and taken through design over a four-year period, in cooperation with federal agencies and following both the NEPA (National Environmental Policy Act of 1969) process and CEQA (California Environmental Air Quality Act of 1970) regulations. Subsequently, in 2002 the Quantm system was contracted in order to help achieve the objective of reducing project environmental impacts, while demonstrating a significant time savings benefit in the process. Per NEPA and CEAQ requirements, Quantm was used to consider "all reasonable alternatives" within the corridor. As the study recalls,

> "The application of the Quantm system and methodology greatly improved the collaboration between the engineering and environmental teams involved with the project, and workshops that would normally run over a four-month period were completed in just two weeks."

Indeed, Quantm eliminated the need for continuously meeting and regrouping over many months in order to investigate and develop alternatives, quantities, impacts, and costs. As an intangible, the study observes how Quantm maintained the momentum of the project by keeping all participants speedily working toward the same objective, thereby "avoiding the inherent resistant/ownership that arises when a planner has taken months to develop a particular alignment."

Even though minimizing costs is an ongoing goal in project design, the Transportation Corridor Agencies primary challenge "was to integrate the multiple and complex environmental, urban and other land-use constraints into the planning process to reduce the environmental impacts of the preferred alternatives," notes the 2005 TRB Planning Applications Conference, Corridor Study paper.

In a tabular comparison of three Quantm-derived versus CAD-derived alternatives provided in the study, Quantm delivered the initial two alignments with a projected construction cost savings of either $100 million or $125 million, while demonstrating a third alignment estimated at $428 million below the CAD-derived alternative. These savings were a result of reducing the excavation quantities and mass-haul needed to obtain finished road grade. The Quantm alignments were said to more closely follow the natural contour of the land while still meeting all necessary design criteria. Simply stated, the less excavation needed, the lower the project costs. The study adds that while Quantm was not utilized as a replacement for GIS or CAD systems – referred to as "conventional tools for infrastructure planning applications" in the study - it operated in tandem with them instead by guiding their utilization in a much more efficient direction.

Another time-saving benefit of using Quantm in this instance was the quick modification of constraints, by delivering refinements of the alignments within two business days, which showed the impact of the changes from an environmental, engineering, and cost perspective. It also produced an “audit trail” for the project “that demonstrated a comprehensive investigation of all alternatives,” according to the study.

Additional benefits of utilizing Quantm over traditional methods (which produced the original alternatives) for this project are listed below, under **“**Environmental and Social Impacts” in the study:

- Reduced impacts to riparian ecosystems by 17, 58, and 68 acres in three separate alternatives (albeit with *increased* impacts to upland resources);
- Reduced impacts to Coastal Sage Scrub by approximately 50 acres;
- Avoided Pacific Pocket Mouse habitats entirely, thereby evading potential mitigation involving wildlife relocations;
- Avoided existing landslide areas, thereby decreasing the remedial grade for the refinements, which reduced the disturbance limits. The refined alternatives also reduced the earthwork quantities from the original alternatives by more closely conforming to the natural terrain;
- The refined alternatives eliminated the need to displace 32 homeowners by taking their properties, as proposed in the original alignment, thereby avoiding expensive mitigation processes for potentially displaced residents; and
- Minimized impacts to existing utilities by inputting their locations into Quantm and allowing the system to evaluate alternatives that avoided them entirely. This reduced impacts to sensitive areas, since the utilities would not have to be located to currently undisturbed areas.

This study concurs with the generally positive assumptions found in other reports and studies regarding the use of Quantm over conventional planning and engineering processes. For the Foothills Transportation Corridor-South project, Quantm clearly reduced the time required for alternatives design and analysis, as well as saving potential expenditures in construction by locating the least environmentally and socially sensitive corridors, along with the most preferable geographic alignment with minimal elevation and grade changes.

Goose Creek Bypass

The objective of this highway project was to plan a new segment that would bypass Goose Creek Canyon (Idaho). The alternatives considered by the project team included upgrading the existing highway (called a "steep, sharp-curved roadway" in the study) or providing a new 4 to 7-mile route to improve safety on SH 55 in Central Idaho, approximately 100 miles north of Boise between the towns of New Meadows and McCall. The study mentions how "bypassing Goose Creek Canyon would avoid many problems including: narrow 22-foot wide roadway (ROW), steep 7% grades, shaded areas due to a lack of sun exposure that can lead to frequent icing conditions in winter, poor curvature, low driving speeds, and inadequate passing opportunities." Additional environmental considerations reflected in the data were wetlands, Northern Idaho ground squirrel and eagle forage habitats, and known cultural sites (i.e., Section 4(f) recreational and historic properties). In order to comply with NEPA process requirements, the project team partnered with Quantm to establish a course for alternatives screening, while using ArcGIS technology in tandem. The screening process developed - using both Quantm and ArcGIS - addressed the challenges for determining new highway corridor alternatives, which were, in turn, to be documented in either an EA or EIS. It also evaluated the possibility of improving the existing highway, but the upgrade alternatives returned by Quantm proved to be 2-3 times more costly than building a new alternative outside of Goose Creek Canyon, notes the study.

With regard to labor and time savings realized by using Quantm, the study points out they were able to quickly change environmental and engineering criteria and generate new alignments that the team could review within days, adding, "This shows that you can investigate alternative scenarios comprehensively without delaying the project." It also mentions that since Quantm allowed the user to focus on the area of investigation, along with using the refinement capability and/or designating "no-go" zones, it was no longer labor and cost intensive to consider new alternatives that may have been suggested by project stakeholders. An additional benefit of utilizing Quantm was how the system removed subjectivity in alignment location decisions made by the planner. Indeed, Quantm highlighted where constraints could not be met and presented not only favorable alignments, but demonstrated how changes to them would affect construction costs in an unbiased fashion, thereby gaining the trust and confidence of a skeptical public. The study mentions how Quantm's rapid development of alternatives allowed the team to integrate resource agencies' input as well. It observes, "Using Quantm also provides clear, objective evidence as to where it is not possible to avoid particular zones due to reasons such as the impact on other zones, inability to meet safe design criteria, or non-viable cost implications."