GIS SUITABILITY MODELING TO SUPPORT A PIPELINE ROUTE SELECTION

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ABSTRACT

Spatial information has always played an important role in the pipeline route selection process (Opara, 2013). The use of geographic information systems (GIS) to support the pipeline route selection has extensively been discussed (Church, 1992), and it continues to be an area of research as GIS technologies continue to evolve, data availability improves, and the criteria or conditions (terrain, geographic, geophysical, anthropological, etc.) are never the same for different pipeline projects. An effective route will have a direct impact in the pipeline life cycle from design and planning to construction and operation. An appropriate route will have positive implications in financial, time scheduling, social and environmental aspects. This study consists of creating a geo-processing suitability model to determine the best route for a future pipeline in the south of Peru, which would start in a known location in the Amazon forest, cross the Andes Mountains, and arrive at another known location on the Pacific coast. Because of the engineering, environmental, social, regulation constraints there are many variables to consider when identifying the route of a pipeline like: topography (slope of terrain, elevation), urban areas, protected areas, environmentally sensitive areas, archaeological areas, accessibility (roads), national projects, military zones, precipitation, mining activities, etc. ArcGIS technologies are used to process input information; a suitability geo-processing model is the framework to determine areas suitable for a pipeline route, where a linear route is automatically generated. Output results are then shared among stakeholders using alignment sheets and web mapping applications based on ArcGIS. An iterative cycle approach is used, so possible routes are shared and evaluated by end users, and later feedback is used to adjust data or parameters and re-run the model to obtain and share new results. The loop continues until resulting pipeline routes are accepted.

1. INTRODUCTION

The engineering department at Hunt Oil is interested in using GIS to identify a possible pipeline route (or corridors). The result will allow the department to focus on analyzing certain path(s) (corridors) suitable for pipeline construction. Peru is a country where the larger oil and specially gas fields are located in the Amazon region, and pipelines have been built to transport product to the coastal facilities throughout the Andes Mountains. Pipeline lengths are usually in the hundreds of miles. Pipeline route design in these conditions is always a challenge because of the difficult geography. Since a pipeline construction in Peru is a capital intensive project and the subsequent operations is an activity expected to be done throughout many years, the decision of a pipeline route has to consider as many variables as possible. "Choosing the shortest, most direct route is always a goal for capital expenditure reasons, but many important goals exist simultaneously in the route selection project and at times these goals may conflict" (Yildirim, 2007).

Spatial information has always played an important role in pipeline routing, from traditional paper maps where engineers would "draw" the route, to geo-processing models that automate the engineer's criteria to identify the route. Selecting the pipeline route is a location based decision that has to be made carefully while considering many factors, not only engineering criteria but also environmental, social, urban, archaeological, legal among others. "The most valuable support for locational decision making is offered by a geographic information system (GIS)" ((Malczewski, 1996)) because spatial information is required during this process, geographic information system (GIS) can easily be integrated as the framework for the decision support system and attempt to provide with alternative routes. The decision support system could become a geo-processing workflow, and all the criteria factors for the pipeline route decision would have to be input as layers of spatial information with subcategories.

Data gathering depends on what information is required, what is available and what data the project can afford to acquire. Engineering, geophysical, environmental, political, social, economic, and regulatory constraints are factors that interact to define the possible routes. These constraints establish the data that is required to carry out this analysis. Diverse information makes the data gathering more challenging because of the different data sources, data availability, scales and resolution of the data. This study uses information publicly available.

ArcGIS is the software framework for data processing and for data sharing. All of the above mentioned data sets are used as spatial information, are assigned weights, converted to raster, and processed using Spatial Analyst to create a Cost Surface, and later the "Cost Path". This will provide an idea of a pipeline route or "corridor" where a potential pipeline could be laid down. Since the approach in this study is to loop through iterations of data processing, output routes sharing and user feedback, geo-processing models are extensively used. Geo-processing models automate and document the process, and also allow for parameters adjustment and re-execution for new results to be evaluated. Data sharing is a very important part of this study, as there is a wide audience to evaluate the pipeline route, effective and timely communication of the output pipeline route will enable a fast end users' evaluation that will feedback the model, and a new processing iteration can be promptly initiated with new data or adjusted parameters.

2. OBJECTIVE

The objective of this project is to use GIS technologies to support the Engineering department of Hunt Oil to identify the best route for a future pipeline in the south of Peru, which would start in a known location in the Amazon forest and would arrive at another known location on the Pacific coast. The process should consider engineering requirements (topography, elevation, slopes) as well as legal, environmental, archaeological and social constraints.

3. DATA REQUIRED

The data required to identify the best pipeline route depends on the engineering requirements and other criteria considered for the analysis.

Engineering constraints:

- Avoid elevations above than 5,000 meters (16,400 feet)
- Avoid terrain slopes larger than 35 degrees, optimum being less than 5 degrees.
- Avoid areas 20 km (or more) away from roads to aid logistics. Preferred areas are within 5 km to existing roads while minimizing roads crossings.

- Preferred areas are those with no or low risk of geohazards. Avoid areas with high risk of landslides, sand dunes movement, tectonic faults, etc.
- Preferred areas are where annual rainfall is no greater than 500 mm per year.

Environmental, legal, archaeological, and social constraints

- Avoid environmentally sensitive areas like national parks, reserves, sanctuaries, lakes, and minimize river crossings.
- Avoid any urban or populated areas, but areas within 5 km are preferred.
- Avoid national projects, non-permit areas, national defense sites, ports and airports.
- Minimize crossing areas with active mining concessions.
- Avoid national archaeological zones and areas with high risk for social conflicts

Based on the criteria, the data sets required includes: 30m DEM, derived slopes, roads, geological hazards, weather/rain conditions, environmentally sensitive areas, mining concessions, archaeological zones, rivers and streams, areas with social conflicts, urban/populated areas. The different information is shown in the map of Figure 1. Input information is detailed in Figure 6.
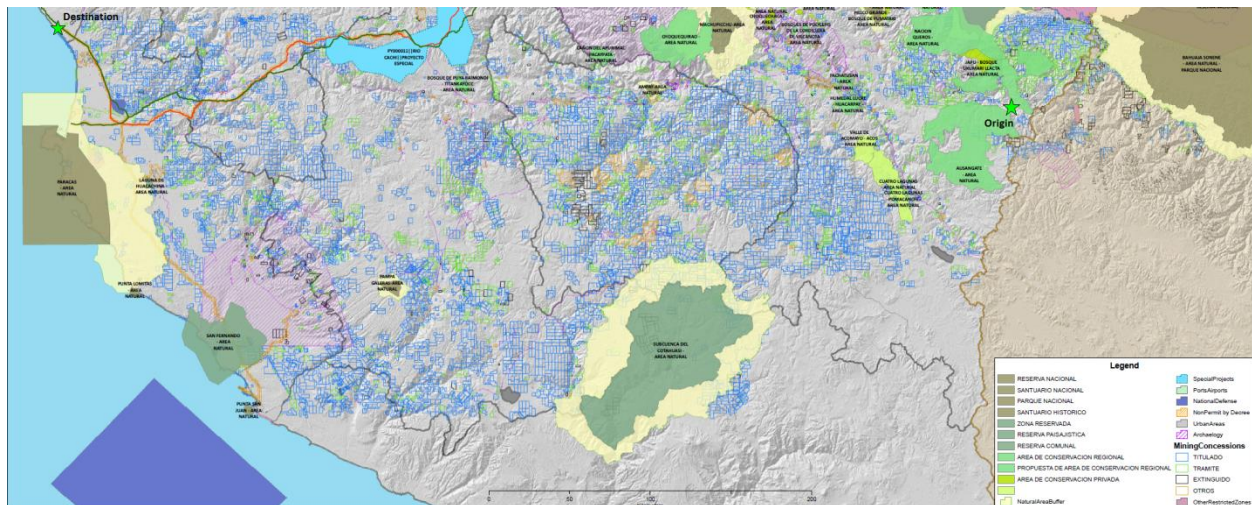

Figure 1: Map of the data sets used for least cost path analysis.

All the data required to accomplish this project has been freely obtained from a diverse group of institutions like:

- ASTER Global Digital Elevation Model Version 2 (GDEM v2) project. This project obtained a DEM with 30 meters spatial resolution which was updated in 2011.

Additionally most of the data has been obtained from Peruvian Government institutions like:

- INGEMMET (Instituto Geologico Minero y Metalurgico del Perú)
- SENAMHI (Servicio Nacional de Metereología e Hidrología del Perú)
- Ministerio de Cultura
- IGN (Instituto Grografico Nacional)
- MINAM (Ministerio del Ambiente)

- SUNARP (Superintendencia Nacional de Registros Publicos)

Even though the data required originated from various Peruvian government institutions, the data was mostly downloaded from web map services available at INGEMMET website (http://geocatmin.ingemmet.gob.pe/geocatmin/).

3.1 Feature Extraction

After reviewing the data, it was determined that literally hundreds of minor water bodies (minor lakes, lagoons, swamps, etc.) were not present in the official cartographic data obtained from Peruvian government institutions, especially water bodies located in the Andes mountains. Water bodies are considered NO-GO areas for this project, because of their importance for local communities and to avoid possible environmental impact.

Since it was crucial to identify, categorize, and avoid crossing water bodies, polygon features of water bodies were extracted from Landsat 8 satellite imagery, which is available at no cost from the USGS Landsat website (http://landsat.usgs.gov) or from Earth Explorer. Figure 2 shows the workflow followed for feature extraction.
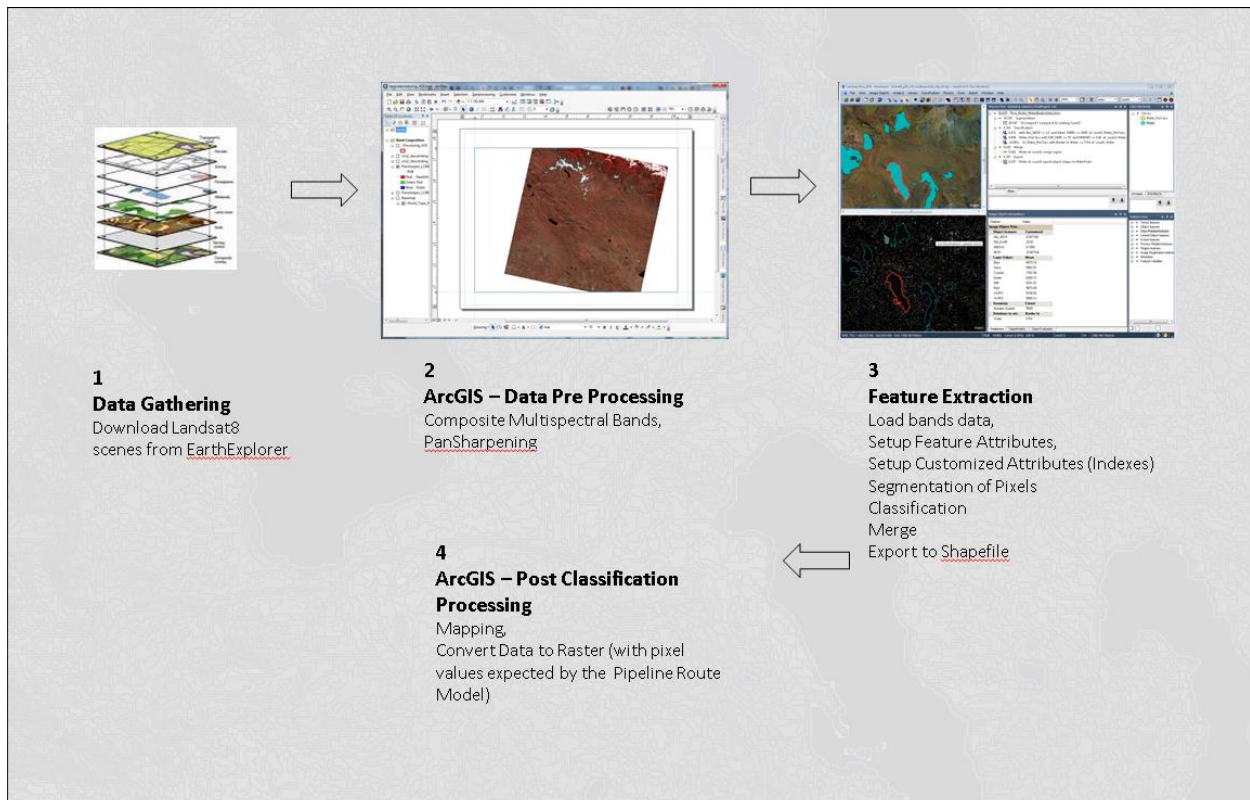

Figure 2: Process for extracting water bodies from Landsat imagery.

Since in the Andes mountains the water bodies' spectral signature can be easily confused with shadows or rocks, the approach for feature extraction was to use "object based feature extraction" (Marangoz, 2006), where an object or "geo-object is defined as an aggregation of points in space-time whose geo-atoms meet certain

requirements, such as having specified values for certain properties" (Goodchild, 2010), this approach proved to capture almost all water bodies and pixels classified as water had a certainty of 99%, percentage determined after a manual quality assurance process on sample areas. Other approaches like "pixel based classification" (Marangoz, 2006) could not discriminate water bodies from shadows, most of the pixels were wrongly assigned as water.

As shown in Figure 3, based on Landsat 8 images (bands 1 to 8), pixels were classified as objects (segmentation) and the following indices were calculated: NDVI (Normalized Difference Vegetation Index), Abs_NDVI (Absolute value of NDVI), MNDWI (Modified Normalized Difference Water Index), Diff_SWIR (Difference of SWIR bands). In the first iteration, segments were selected whose values were Abs_NDVI <= 1.5 and SWIR1 <= 5600. Then from these segments another final selection was made for those segments whose values were Diff_SWIR <=55 and MNDWI >= 0.06. These segments represent water bodies and were merged and exported to polygons in shapefile format.
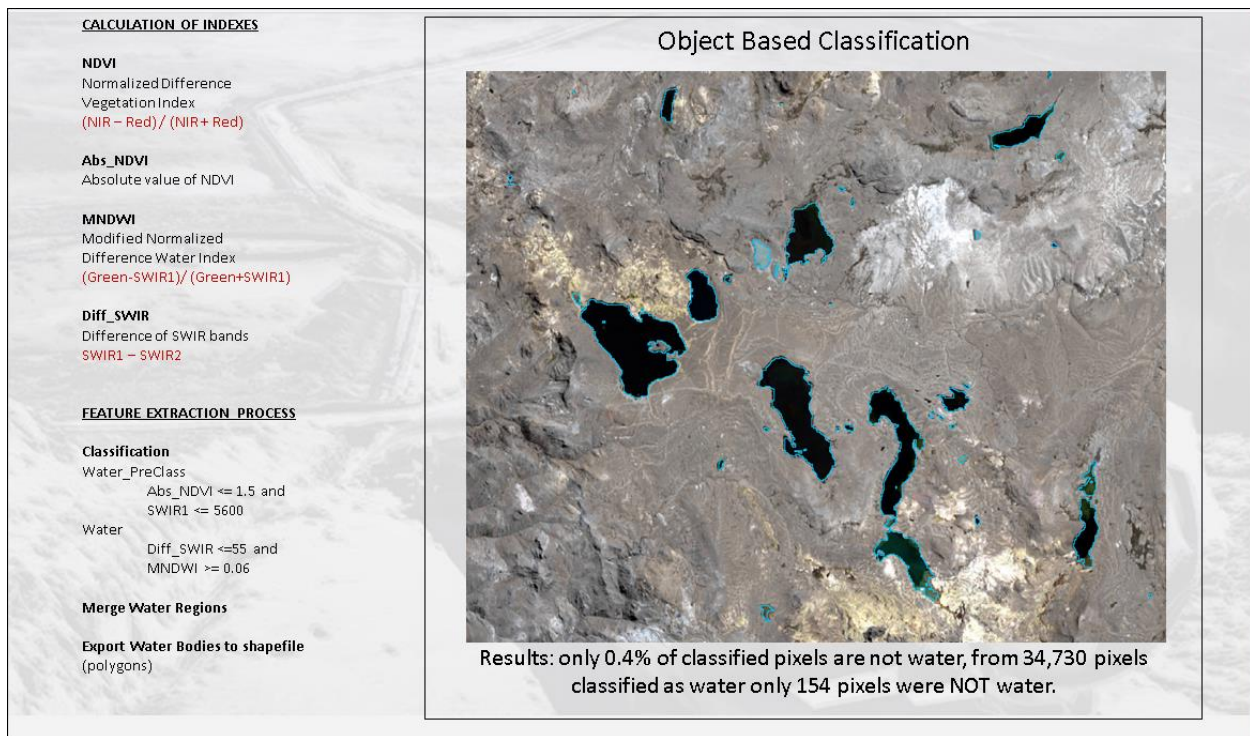

Figure 3: Object based feature extraction process.

The resulting water polygons were later converted to raster and assigned a value of 100, representing NO-GO areas, and included as a raster layer as part of the analysis.

4. STUDY AREA

The project is located in the south of Peru as displayed in Figure 4. The proposed origin is a known location in the Amazon jungle, and the destination is also a known location in the Pacific coast.
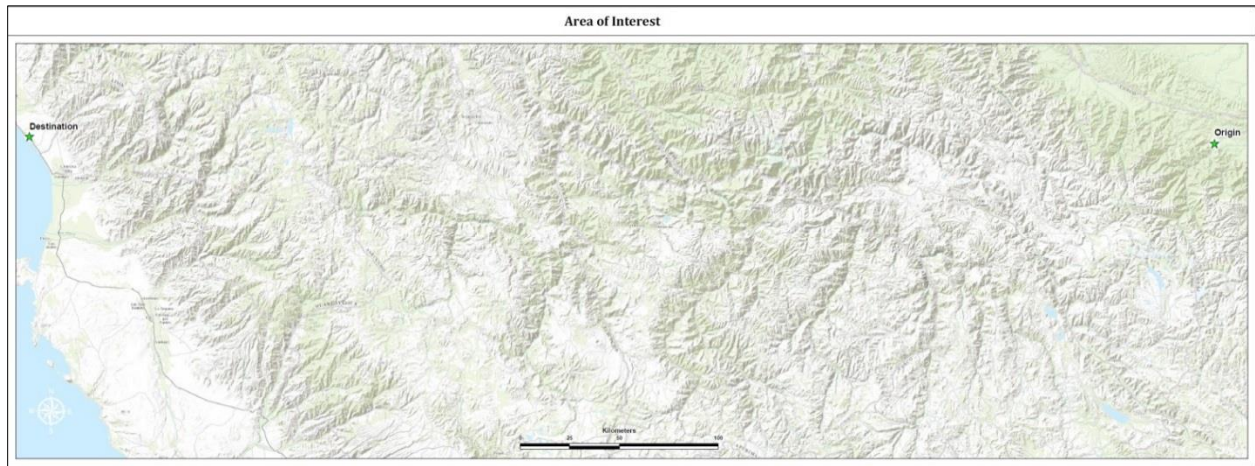

Figure 4: Study Area to define a Pipeline Route (South of Peru).

5. METHODOLOGY

As shown in Figure 5 below, an iterative approach is used. Input data is classified, assigned weights, converted to raster and then a Cost Surface and Least Cost Path are generated using re-usable geo-processing models. These outputs are then shared and evaluated by end users; feedback is later used to adjust data or parameters and re-run the models to obtain new results. The loop would continue until resulting pipeline routes are generally accepted. Since the approach in this study is to loop through processing iterations, geo-processing models are extensively used. Geo-processing models automate and document the process, and also allow for parameters adjustment and re-execution for new results to be evaluated.
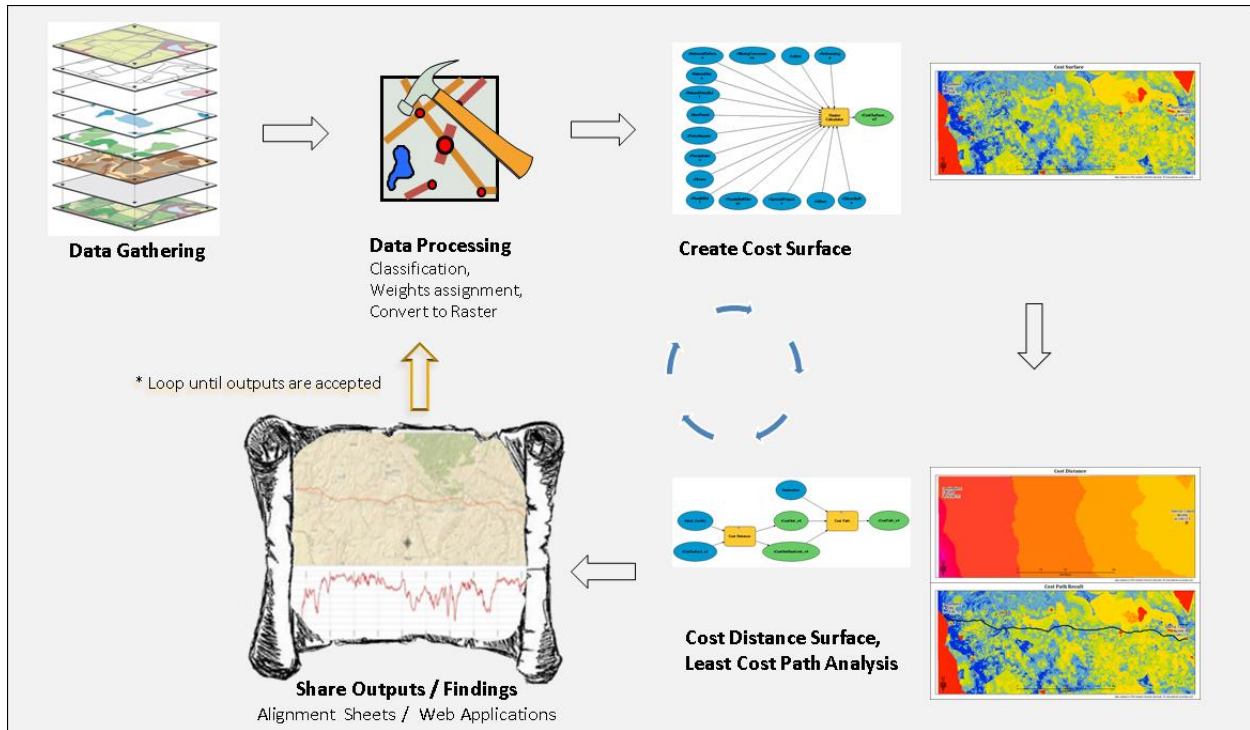
Figure 5: Methodology flowchart description.

Data sharing is a very important part of this study. There is a wide audience to evaluate the pipeline route, effective and timely communication of the output pipeline route will enable a faster end users' evaluation that will feedback the model, and a new processing iteration can be promptly initiated with new data or adjusted parameters. Alignment sheets are map reports that graphically describe pipeline linear entities using different bands to depict the different categories of characteristics a pipeline can have. This study use alignment sheet reports to describe the output pipeline routes. Information is also shared using web mapping based on ArcGIS server technology.

6. DATA PROCESSING

Since the methodology proposed is based on an iterative cycle of processing and data sharing, a couple of iterations have been run as a proof of concept to test the models, to evaluate the criteria and to gather users' initial feedback. The experience and results of those iterations are discussed in Sections 6 and 7. The software used for the data processing is ArcGIS for Desktop 10.3.1 and Spatial Analyst.

6.1 Data Classification

Information required for this study comes from a variety of sources usually as vector format; information is then classified in sub categories. Each vector dataset required some manipulation and transformation to convert data into raster format, whose values (weights) reflect the criteria for an optimum pipeline route analysis. Briefly, the geo-process for each input dataset consists of assigning weights (by adding a "PixelValue" field to store the weight value), and converting vectors to raster for those cell values to which the weights are assigned. Figure 6, describes the input data, and summarizes the process done to

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each data set (and sub category) in order to convert it into a valid raster data set with a weight assigned as pixel value.

Dataset	Source	Categories	Buffer	Add PixelValue Column	Weight	Convert to Raster	Raster
Archaeology	Ministry of Culture	Main sites		Yes	9	Yes	rArchaeology
		Minor sites			7		
Lakes	National Institute of Geography			Yes	100	Yes	rLakes
Mining Concessions	National Institute of Geology	Active		Yes	7	Yes	rMiningConcessions
		Non Active			3		
National Defense	National Institute of Geology			Yes	100	Yes	rNationalDefense
Natural Area	Ministry of Enviromental Affairs	Reserved Area Regional Conservation Private Conservation Others		Yes	5	Yes	rNaturalArea
		Community Reserve Landscape Reserve			8		
		National Sanctuary National Park National Reserve Historic Sanctuary			100		
Natural Area Buffer Zone	Ministry of Enviromental Affairs			Yes	7	Yes	rNaturalAreaBuffer
Non Permit by Decree	National Institute of Geography	Existing Pipelines RoW		Yes	0	Yes	rNonPermit
		Other Restricted Areas			9		
Ports and Airports	National Institute of Geography			Yes	100	Yes	rPortsAirports
Precipitation (historic rain statistics per year)	National Service of Hydrology, Navigation and Weather	0 to 50 mm		Yes	1	Yes	rPrecipitation
		50 to 500 mm			3		
		500 to 1000 mm			5		
		1000 to 3000 mm			7		
		more than 3000 mm			9		
Rivers	National Institute of Geography		Yes (40 m)	Yes	9	Yes	rRivers
Roads	Ministry of Transportation		Yes (20 m)	Yes	9	Yes	rRoads
Roads Buffer Rings		0 to 5,000 m	Yes	Yes	1	Yes	rRoadsBuffRings
		5 to 10 km			4		
		10 to 15 km			6		
		15 to 20 km			7		
Special Projects	National Institute of Geology			Yes	9	Yes	rSpecialProjects
Urban Areas	SUNARP (Real Estate and Public Registry)			Yes	100	Yes	rUrban
Urban Areas Buffer Rings		0 to 1,000 m	Yes	Yes	8	Yes	rUrbanBuffs
		1 to 3 km			5		
		3 to 5 km			3		

Figure 6: Data Classification Table.

6.2 Weights Assignment

The criteria (user constraints) described in section 3, defines what data is required to accomplish this study, and also define if each dataset has to be divided into the different sub categories (if any). On the other hand, figure 6 describes the processing and weight assignment for each vector data set, and states what Peruvian government organization provided the data.

Later as shown in Figure 7 each vector data set is classified into sub categories, and each sub category is assigned a weight. In this study, weights are numbers normally ranging from 1 to 10. Being 1 the most favorable for a pipeline route and 10 the least suitable. Additionally "No-Go" areas, or areas to avoid, get assigned 100 as weight value.

Besides vector data, this study uses a 30 meter DEM. ASTER GDEM which is publicly available by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).

The DEM is used in this study to fulfill some of the initial criteria:

- o   Depending on the elevation, cell values were reclassified. Values greater than 5000 meters were assigned a weight of 100 (No-Go), and elevation less than 5000 were assigned a weight of 1.

o A slope surface was derived from the DEM, and Slope (Terrain difficulty) was reclassified as shown in Figure 7.

The weights assigned to all vector and raster datasets used in this analysis are shown in Figure 7, which also depicts the subcategories for each data set.

SCORES CATEGORIES										
Terrain Difficulty (TC)			**Logistics/Roads (L)**			**No River crossings (RC)**				
Less than 5 degrees	0.5		Access within 5 km	1		One RV-Xing every 10 km or more	1			
5 to 10 degrees	1		Acces within 5 to 10 km	4		One RV-Xing every 5 to 10 km	3			
10 to 15 degrees	1.9		Access within 10 to 15 km	6		One RV-Xing every 1 to 5 km	6			
15 to 20 degrees	3.6		Access within 15 to 20 km	7		More than 1 RV-Xings every 1 km	8			
20 to 35 degrees	9		Access more than 20 km	8						
Greater than 35 degrees	100	No go								
			Geohazards (G)			**Environmental Sensitive Areas (ESA)**				
Weather conditions /Rain (WC)			Do not exist any	0		No Env. Sensitive zones	1			
Less than 50 mm/year	0.5		Low	3		Other minor sensitive zones	5			
50 to 500 mm/year	1.5		Medium	6		Buffer zones	7			
500 to 1000 mm/year	4		High	9		Reserved zone, landscape or community reserves	8			
1000 to 3000 mm/year	6					National Reserve, Park, Sanctuary, big water bodies (lakes, lagoons, ocean).	100	No go		
More than 3000 mm/year	8									
			Social Conflicts (SC)			**Population density (PD)**				
Archaelogical Zones (AZ)			Low Potential	2		More than 5 km to populated areas (towns)	1			
National archaeological zone	9		Moderate Potential	5		3 to 5 km to populated areas	3			
Minor archaelogical zones	7		High Potential	8		1 to 3 km to populated areas	5			
Non archaelogical zones	0					0.5 to 1 km to populated areas	10			
						Less than 500 m	100	No go		
Mining Concesions (MC)			**Overlap with other projects (OWP)**							
No Mining Concesions	0		No overlapping	0						
Granted but not active	3		Overlaping with other RoW	2						
Active	7		Overlaping with others	10						

Figure 7: Weights assignment matrix.

Besides the weights assignment, it's important to notice that not all the data sets have the same importance for the analysis. Some criteria are more important than others, thus some datasets are more important than other. For example environmentally sensitive areas are more important than rainier conditions. To address this difference in importance, each data set should have assigned an "importance factor."

The method to calculate the "importance factor" will be defined by a datasets comparison matrix. The idea is to compare each dataset against all other datasets, this idea was derived from Analytic Hierarachy Process (AHP) (Gemitzi, 2007) (Berry, 2003). For example if dataset A is more important than dataset B, dataset A will be assigned 2 points and dataset B will be assigned 0. If datasets have the same relevance, each dataset will be assigned 1 point. At the end, each data has a summary of points and gets assigned a proportional percentage, which will be used as weight.

Compared to other arbitrary options for weight assignments, this was easy to explain to final users (engineering and other departments) and participation was high in this stage. Figure 8 depicts a sample of the weights assignment matrix. Each dataset (row) is compared against the other data sets (in columns), getting assigned points from 0 to 2. 0 = less important, 1 = same importance, 2 = more important. At the end of each row the points are summed, with the points represent a percentage of the total points available. This percentage is the "Importance Factor".

FACTOR	Terrain Difficulty	Weather Conditions	Logistics (Roads)	Geohazards	No of river crossings	Environ. Sensitive Areas	Archaeological Sites	Population Density	Social Conflicts	Mining Concesions	Overlap with Other Projects		"Importance" FACTOR
Terrain Difficulty		1	1	1	2	0	0	1	1	2	2	11	10.0%
Weather Conditions	1		1	1	2	0	0	0	0	0	2	7	6.4%
Logistics (Roads)	1	1		0	1	0	0	0	0	2	1	6	5.5%
Geohazards	1	1	2		2	1	1	2	2	2	1	15	13.6%
No of river crossings	0	0	1	0		0	0	0	0	1	1	3	2.7%
Environ. Sensitive Areas	2	2	2	1	2		2	1	1	2	2	17	15.5%
Archaeological Sites	2	2	2	1	2	0		2	1	1	2	15	13.6%
Population Density	1	2	2	0	2	1	0		0	2	1	11	10.0%
Social Conflicts	1	2	2	0	2	1	1	2		2	1	14	12.7%
Mining Concesions	0	2	0	0	1	0	1	0	0		1	5	4.5%
Overlap with Other Projects	0	0	1	1	1	0	0	1	1	1		6	5.5%
	9	13	14	5	17	3	5	9	6	15	14	110	100%
	20	20	20	20	20	20	20	20	20	20	20		

Figure 8: Importance Factor matrix.

6.3 Cost Surface

After each dataset (and sub categories) get assigned a weight value, each dataset is converted into raster format where pixel values represent the weight. The raster datasets are used to calculate a Cost Surface.

The Cost Surface is calculated by a Weighted SUM method using the pixel value (weights) multiplied by the "importance factor".

Cost Surface = $0.1 * TD + 0.064 * WC + 0.055 * L + 0.136 * G + 0.027 * RC + 0.155 * ESA + 0.136 * AS + 0.1 * PD + 0.127 * SC + 0.045 * MC + 0.055 * OWP$
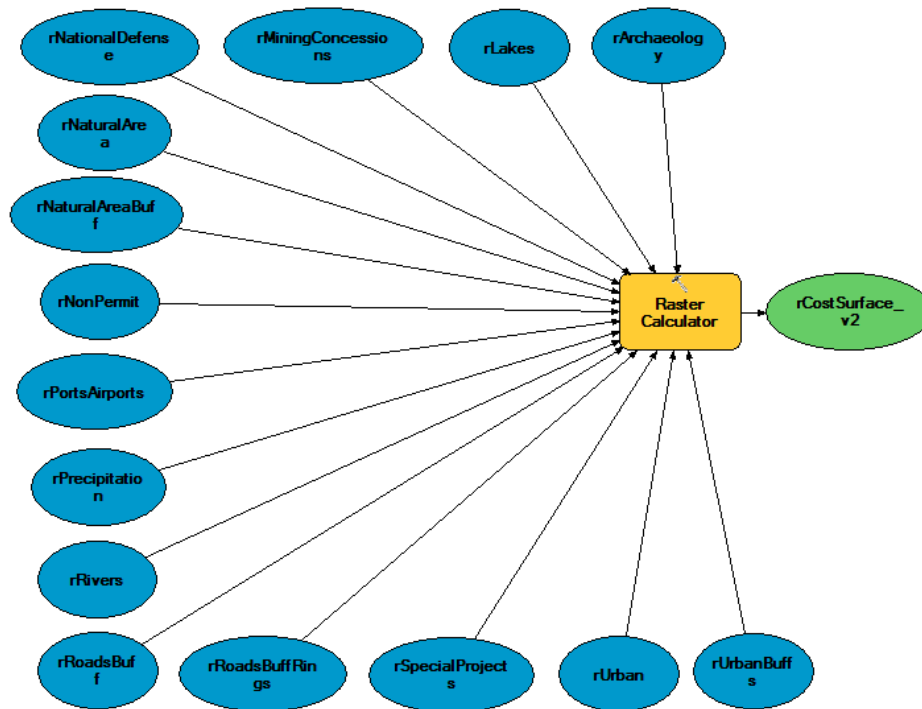

Figure 9: Geo-processing model to calculate the cost surface.

Figure 9 displays the geo-processing model used to create the Cost Surface. The formula to create the Cost Surface was basically a weighted addition of all pixel values. In order to avoid null values to mislead Cost Surface cells, the formula was replaced to assign 0 to NoData values prior the addition.

Figure 10 shows the resulting Cost Surface in one of the iterations. Weights assignment and area of influence (extent) were changed many times in order to provide a meaningful and more "realistic" cost surface.
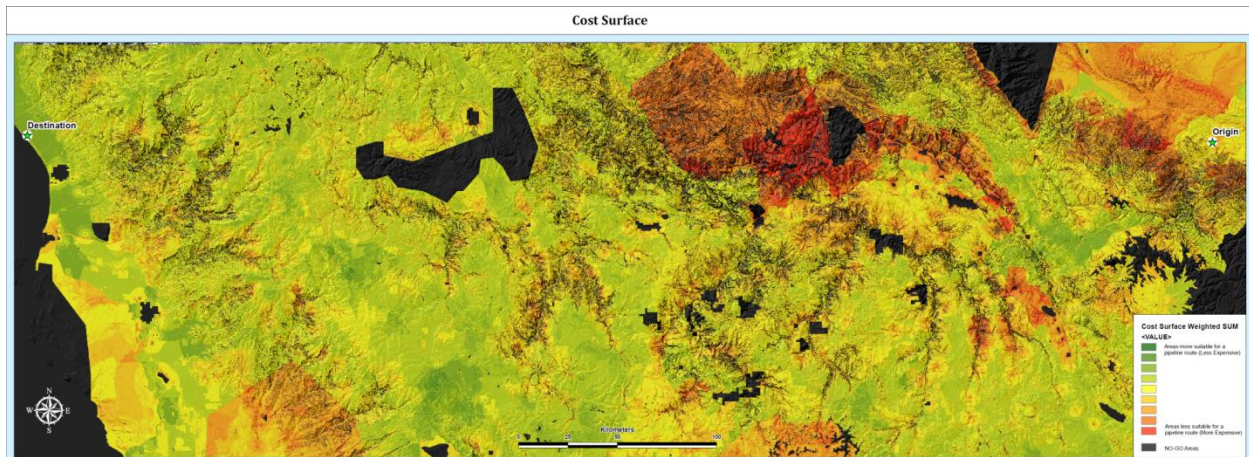

Figure 10: Cost Surface that summarizes the weighted sum of all input datasets.

Figure 10 depicts a choropleth map where areas in green are more suitable for the pipeline route while areas in red are less suitable. Areas in black are "No-go" areas.

6.4 Least Cost Path

Once the Cost Surface has been created, this information will be the input to determine the optimum pipeline route by calculating the Least Cost Path.

Using ArcGIS Spatial Analyst, the first step to use the Cost Distance tool is to create two pre-requirements for the Least Cost Path: a "Cost Distance" surface and a "Cost Distance Back Link" surface. Given the Cost Surface and a source (origin) location, the Cost Distance represents for the "cost" to travel to the source location for each cell (pixel). At the same time the "Cost Distance Back Link" surface represents the direction for each cell (pixel) to travel to the source location following the least cost path.

Later a "Cost Path" will provide users with an idea of a pipeline route or "corridor" where a potential pipeline could be laid down.

These tools have been grouped in a geo-processing model shown in Figure 11.
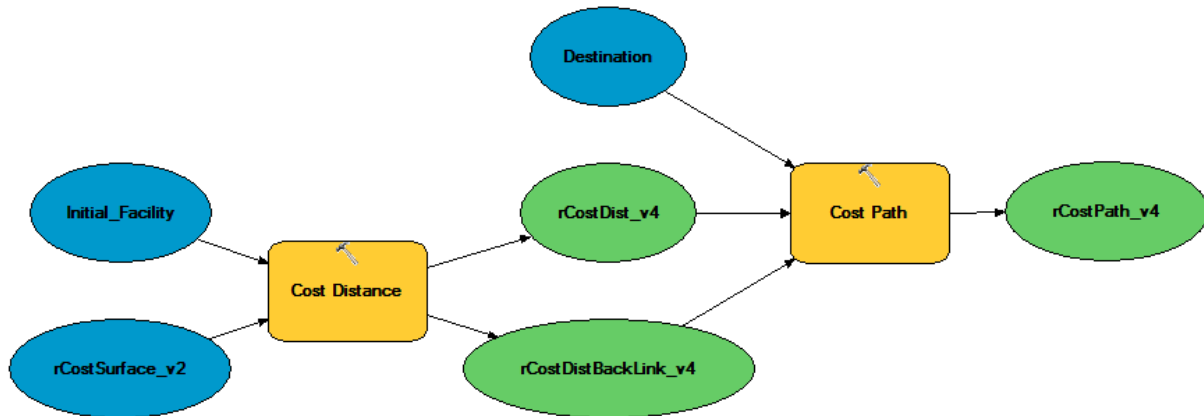
Figure 11: Geo-processing model to create the Cost Distance, Cost Distance Back Link, and Cost Path outputs

The initial outputs of the above mentioned model are shown in Figure 12 and 13, which displays the Cost Distance surface (rCostDist_v4 in Figure 12) and the Cost Distance Back Link (rCostDistBackLink_v4 in Figure 13).
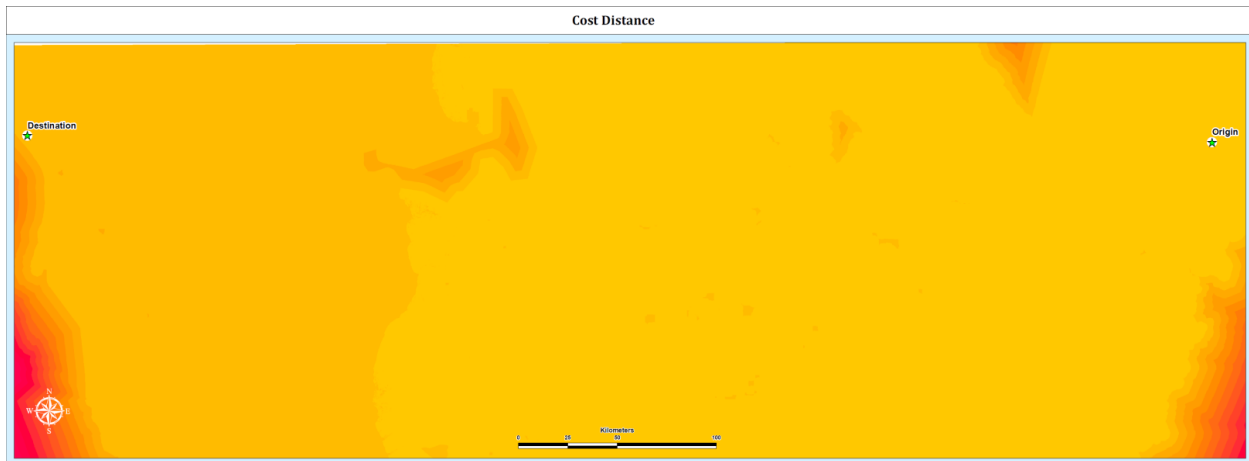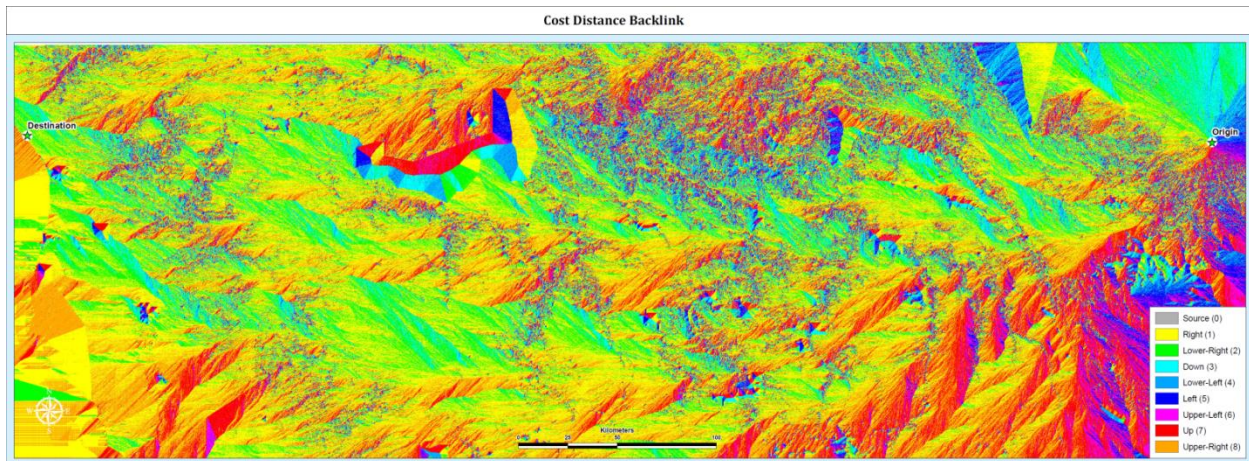

Figure 12: Cost Distance surface

Figure 13: Cost Distance Back Link surface

Using the "Cost Distance" and "Cost Distance Back Link" surfaces, the Cost Path tool determines a corridor(s) or areas suitable for a pipeline route that would connect the initial and final locations.

7. PREMILINARY RESULTS

The identified "Cost Path" raster is then converted to a polyline as shown in Figure 14. The polyline was then converted to a linear referencing entity to create a Polyline with M (Measure) and Z (Elevation) values, to determine the elevation profile and an approximation to a real slope (or 3D) distance.
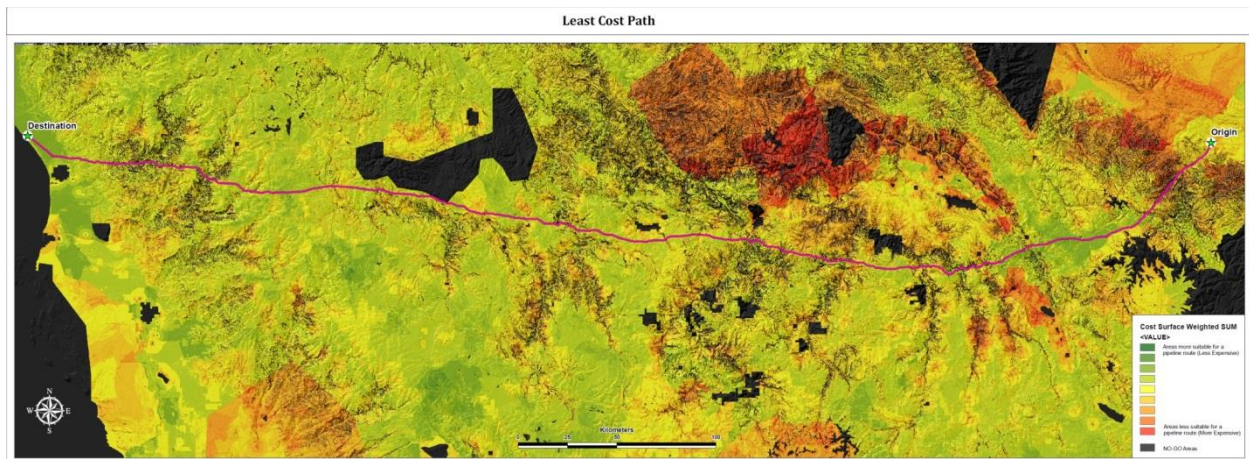

Figure 14: Least Cost path, preliminary attempt.

The least cost path, line shown in red in figure 14, is the most effective pipeline route given the data and parameters (weights, importance factor). Parameters can be changed, data modified and geo-processing models can be re-run to recalculate the route, and the iteration can continue until a route is accepted by stakeholders. Figure 15 compares the "automatic" route against "manually" defined routes.
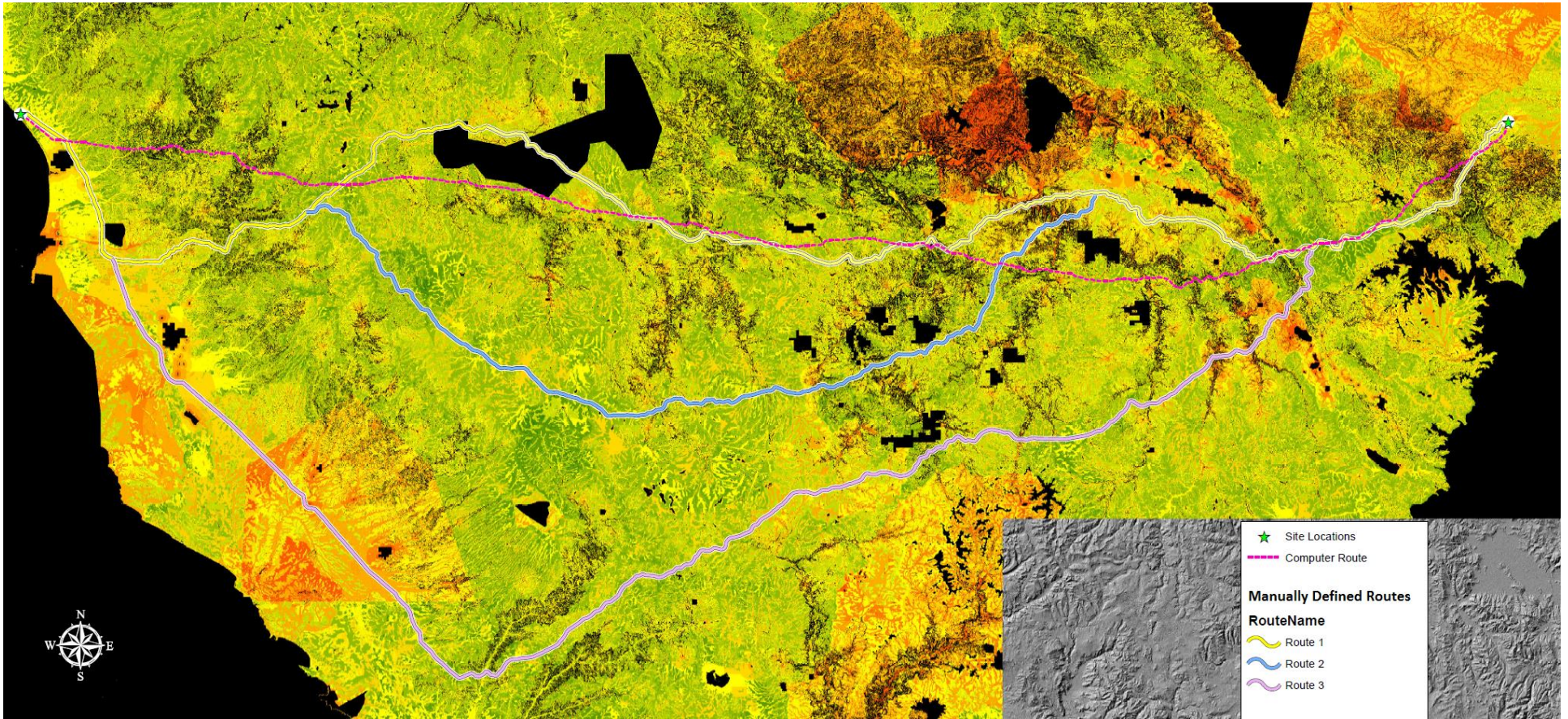
Figure 15: Least Cost path, comparison of automatic against manual routes.

Figure 15 shows the automatically calculated route (in magenta) from Figure 14 that is the shortest path compared to other three manually defined routes. Route 1 (manual) is similar in some sections to the automated route, but it crosses some NO-GO (Black) areas. The difference in lengths describes the usefulness of the suitability model:

Route 1	795,000 km
Route 2	825,000 km
Route 3	872,000 km
"Computer" Route	**705,000 km**

8. DATA SHARING

Data sharing is a very important part of this study, there is a wide and dispersed audience to evaluate the pipeline route. Effective and timely communication of the output pipeline route will enable faster evaluation by end users that will provide feedback for the model, and a new processing iteration can be promptly be initiated with new data or adjusted parameters.

The initial iterations of the geo-process helped to identify two products that final users (Engineering department) consider the most important after all the analysis:
- Cost Surface
- XYMZ Polyline that represents the least cost path

This study considers two main communications means to distribute the identified pipeline routes and the cost surface: Alignment Sheets map reports and a web application. Both are based on ArcGIS for desktop and server.

8.1 Alignment Sheet

Alignment sheets are map reports that are an effective means to describe the multiple characteristics of linear entities like pipelines. Besides the map itself, a profile and a series of horizontal bands (see graphic 16 below) that describe the different characteristics along the pipeline route, which can be used to gather feedback to adjust the model. Figure 16 depicts the output pipeline route in an Alignment Sheet layout design. The profile shows the topography including the Andes Mountains and the bands describe the different categories of properties like crossings, environmental classes, landscape classes, etc. This type of map report was generated using a .NET AddIn for ArcMap ArcGIS Desktop. "Map reporting becomes fundamental for a successful GIS implementation" (Gamarra, 2011)
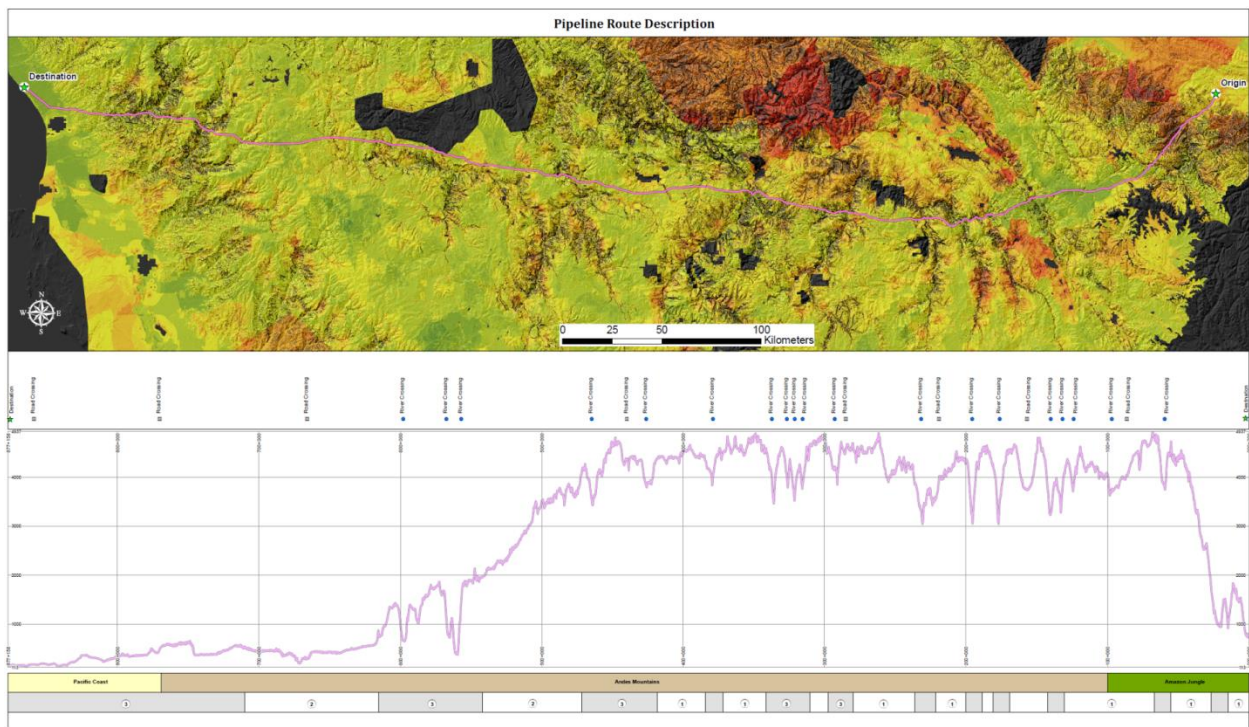

Figure 16: Alignment Sheet sample that would describe the resulting pipeline route.

8.2 Web Application

Since some of the audience might be dispersed in different offices, a web application is an effective way to distribute the spatial information about this study. Based on ArcGIS technology, an intranet web application can publish the input information and also the output pipeline route(s), making it possible for decision makers to analyze the outputs and navigate through the data.

Figure 17 shows a sample of a web GIS application that can publish spatial information about this study. Web map applications for this project were always based on application templates from ArcGIS Silverlight SDK.
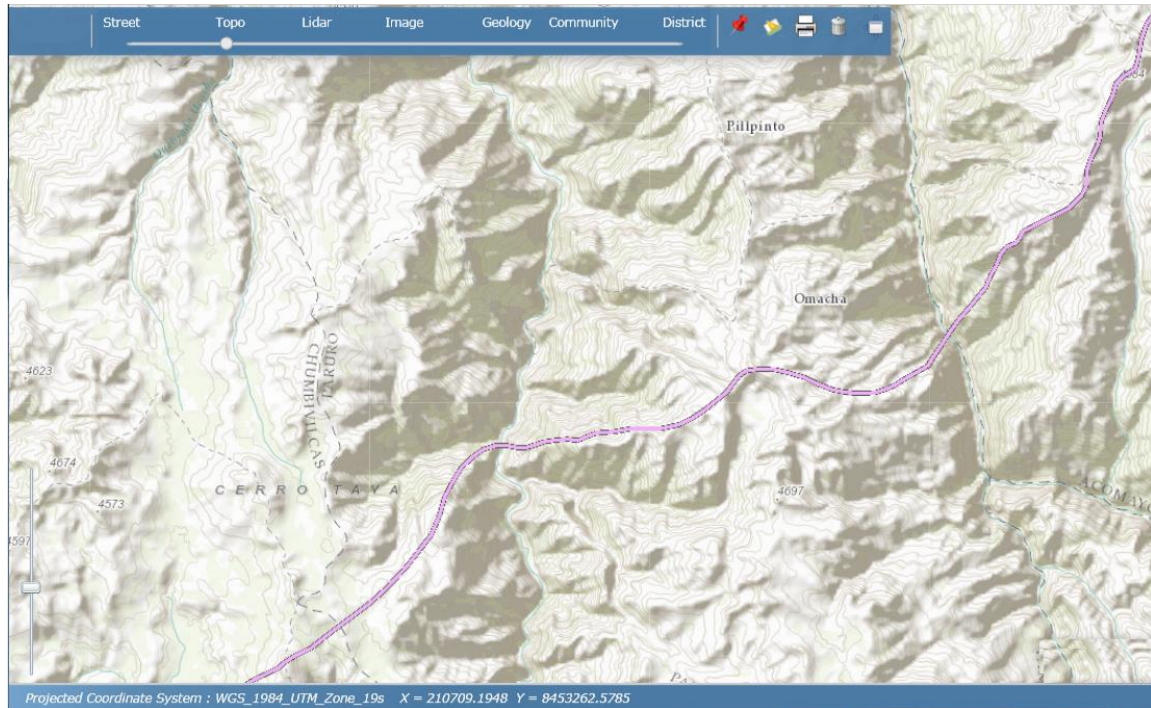

Figure 17: GIS Web application sample.

9.   PROJECT TIMELINE

The timeline for this project was aligned with the schedule suggested by the Engineering department, and later adjusted by the data gathering that took longer than initially expected. The iterative cycle approach of this project and the use of models allowed adding new data at later stages not really affecting the schedule. These are the main milestones for the project:

Data Gathering and initial analysis 09/2014

Proof of concept, project proposal and peer review 10/2014

Data and suitability model refinement 12/2014

Data sharing design (alignment sheets and GIS website design). 02/2015

Project Presentation 07/2015

10. CONCLUSION

The various studies and continues research on location based decision models, and particularly on the pipeline route selection topic, provide a good starting point for this type of projects. Then ideas can be refined and tailored since criteria or conditions (terrain, geographic, geophysical, anthropological, etc.) are never the same for different pipeline projects. Additionally, recent advantages in GIS technologies provide the possibility to automate this process, by taking advantage of geo-processing models which can be easily modified, adjusted, and can re-run when parameters are changed.

For this project all data was converted to raster format, which was the input for the geo-processing models. Geo-processing models were the key for the iterative cycle approach, so the results produced were shared with users whose feedback was later used to re-run the models. It was also important to have an efficient way to share data, in a format easy to understand for users. New routes were immediately available through web GIS applications, and details describing the route were shown in Alignment Sheet PDF map reports.

Overall this project's results proved to be more efficient than "manually" identified routes, whose location or path was easy to defend and support. Even though the results, it's interesting to note that final users considered Figure 10 (Cost Surface) and Figure 16 (Cost Path / pipeline route with profile) the most valuable outputs. The cost surface might be used to "manually draw" an alternative pipeline route, and the geo-processing models could to be reused for smaller segments to provide Engineers with an additional alternative to compare with..

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