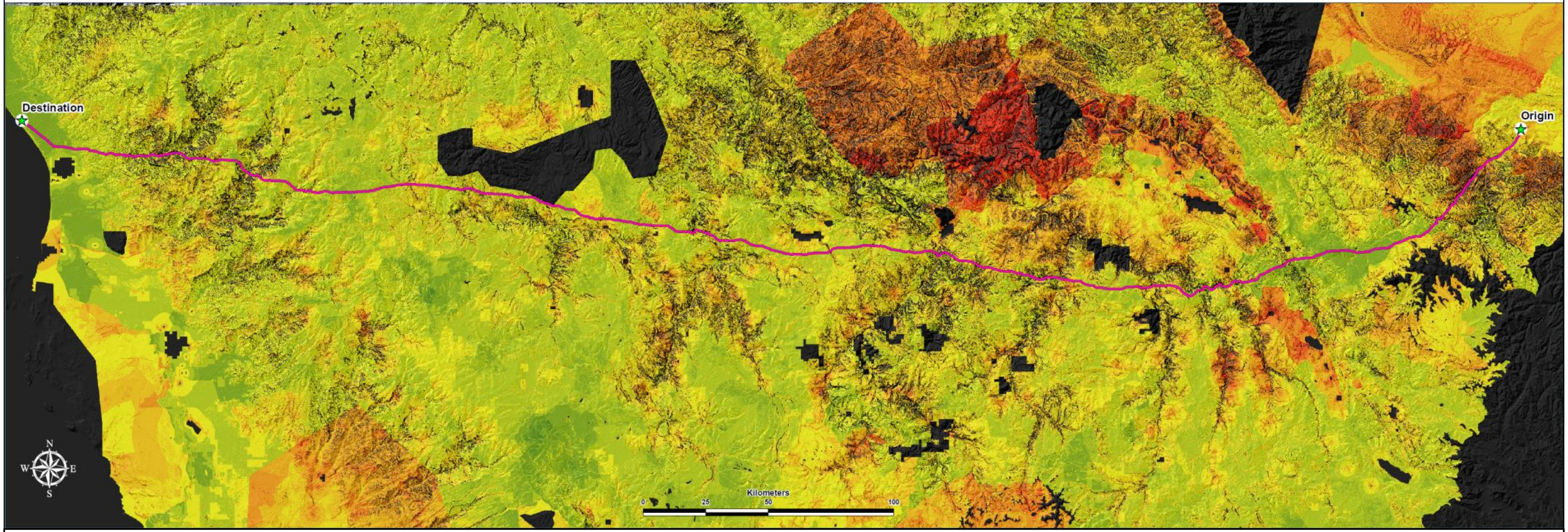
GIS suitability modeling to support a pipeline route selection



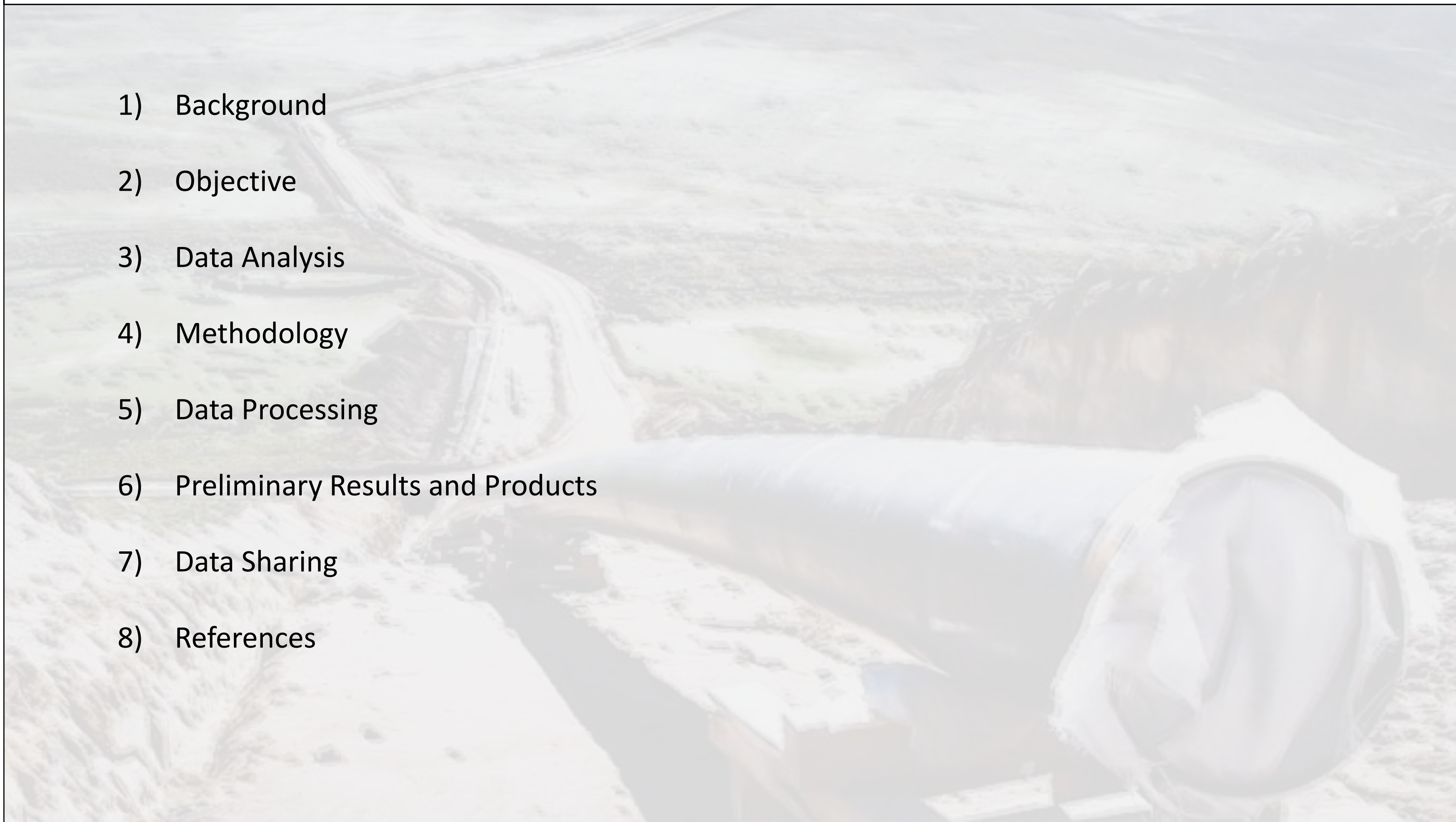
Americo Gamarra

Senior GIS Analyst – Hunt Consolidated Inc.

Penn State MGIS Candidate – Advisor Dr. Patrick Kennelly

ESRI UC - July, 2015

Overview



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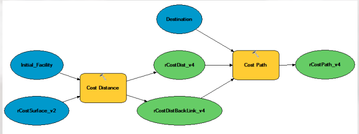
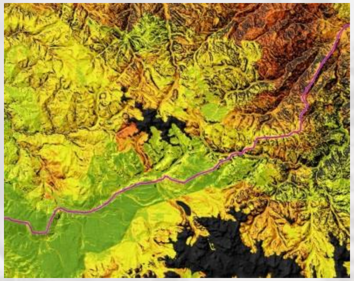
Background

- Pipelines are used to transport large volumes of oil or gas over long distances.
- Selecting the optimum pipeline route is the first key step in the pipeline design and construction. An effective route will have direct impact financially, and throughout the pipeline life cycle during construction and operations phases.
- *“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 engineers criteria to identify the route.

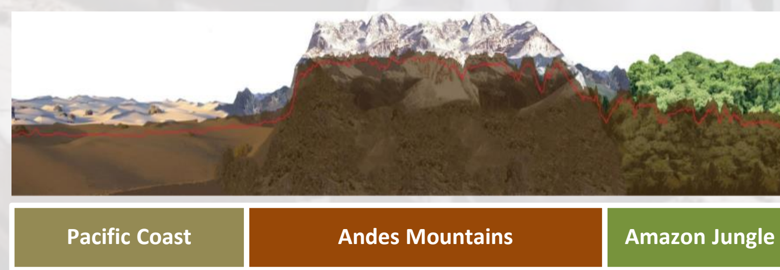




Background

- The use of GIS to support the pipeline route selection has extensively been discussed, and it continues to be an area of research as GIS technologies continues to evolve, data availability improves, and the criteria or conditions (terrain, geographic, geophysical, anthropological, etc.) are never the same for different pipeline projects.

- Peru is a country where the larger oil/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 route design is always a challenge because of the difficult geography.



Objective

Use GIS technologies to support the Engineering department 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 coast. Consider engineering requirements (topography, elevation, slopes) as well as legal, environmental, archaeological and social constraints.

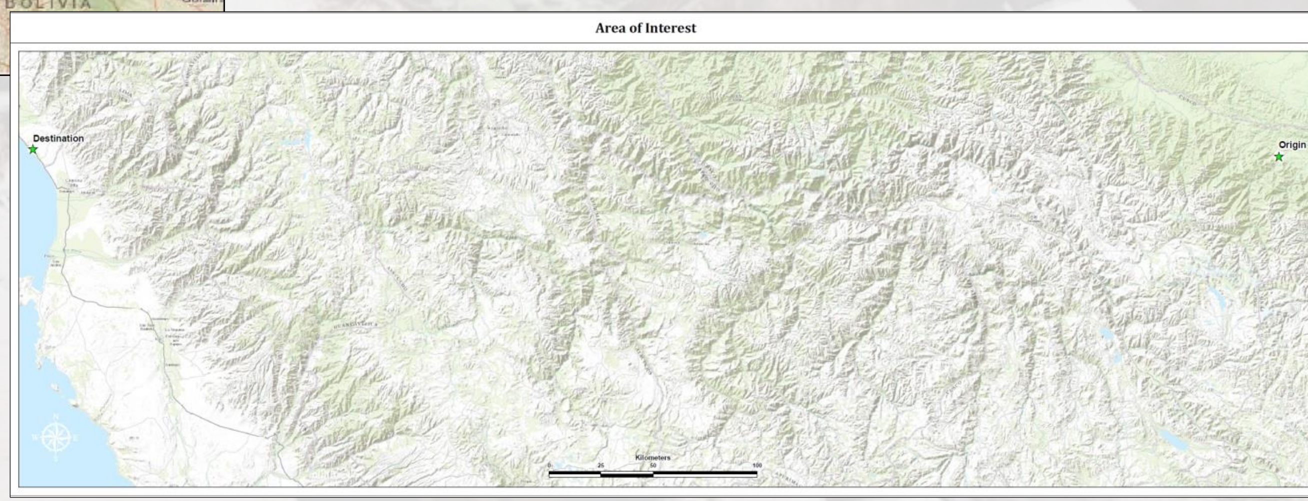
To accomplish this objective these are the main tasks:

- Gather data and information required.
- Generate maps to support “traditional” route identification.
- Create a geo-processing model to automatically identify the route or corridors for pipeline
- Share findings and outputs with stakeholders throughout the company by using traditional paper maps describing routes (Alignment Sheets) and also using web map applications.

Data Analysis

Area of Interest

Locations are referential, intended for educational purposes only.



Data Analysis

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.
- From logistics perspective, avoid areas 20 km (or more) away from roads. Preferred areas are within 5 km to existing roads. Minimize roads crossings.
- Preferred areas are those with no or low risk geohazards, and try to 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.

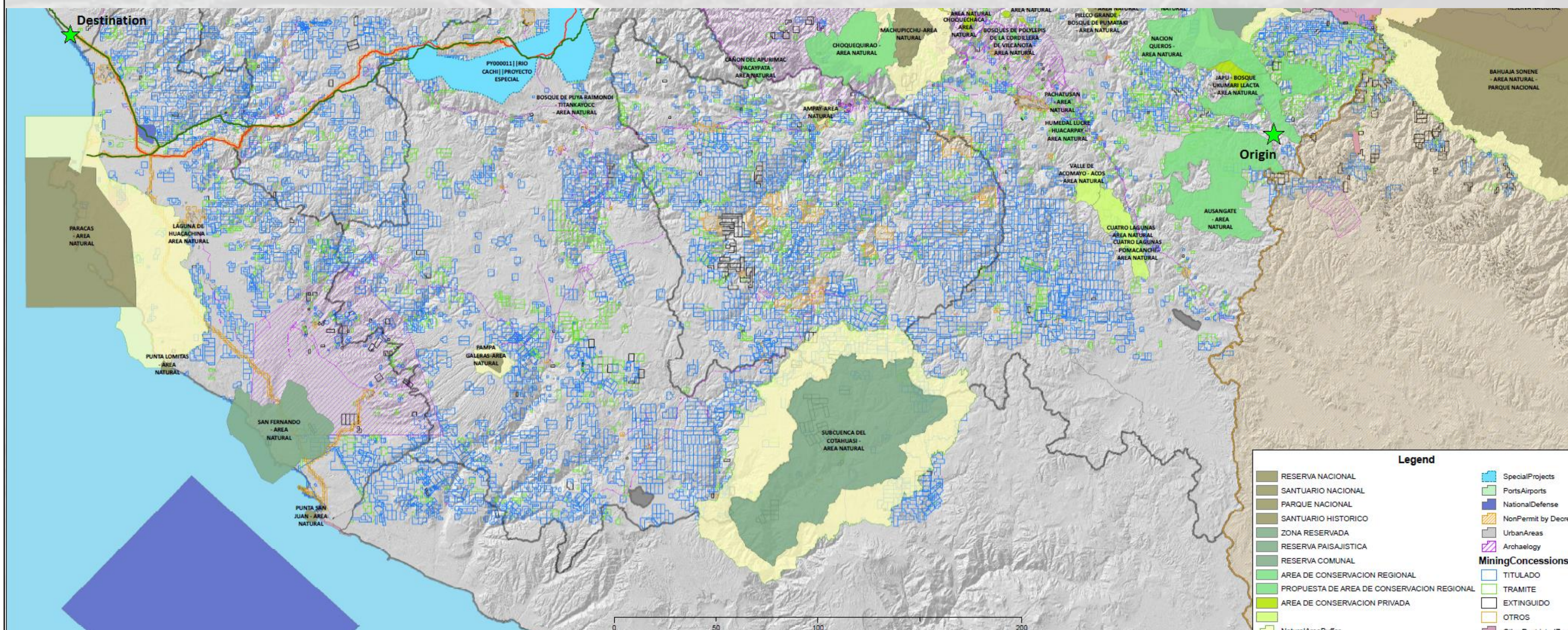
Environmental, legal, archaeological, and social constraints

- 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, national defense, ports and airports.
- Minimize crossing areas with active mining concessions.
- Avoid national archaeological zones and areas with high risk for social conflicts

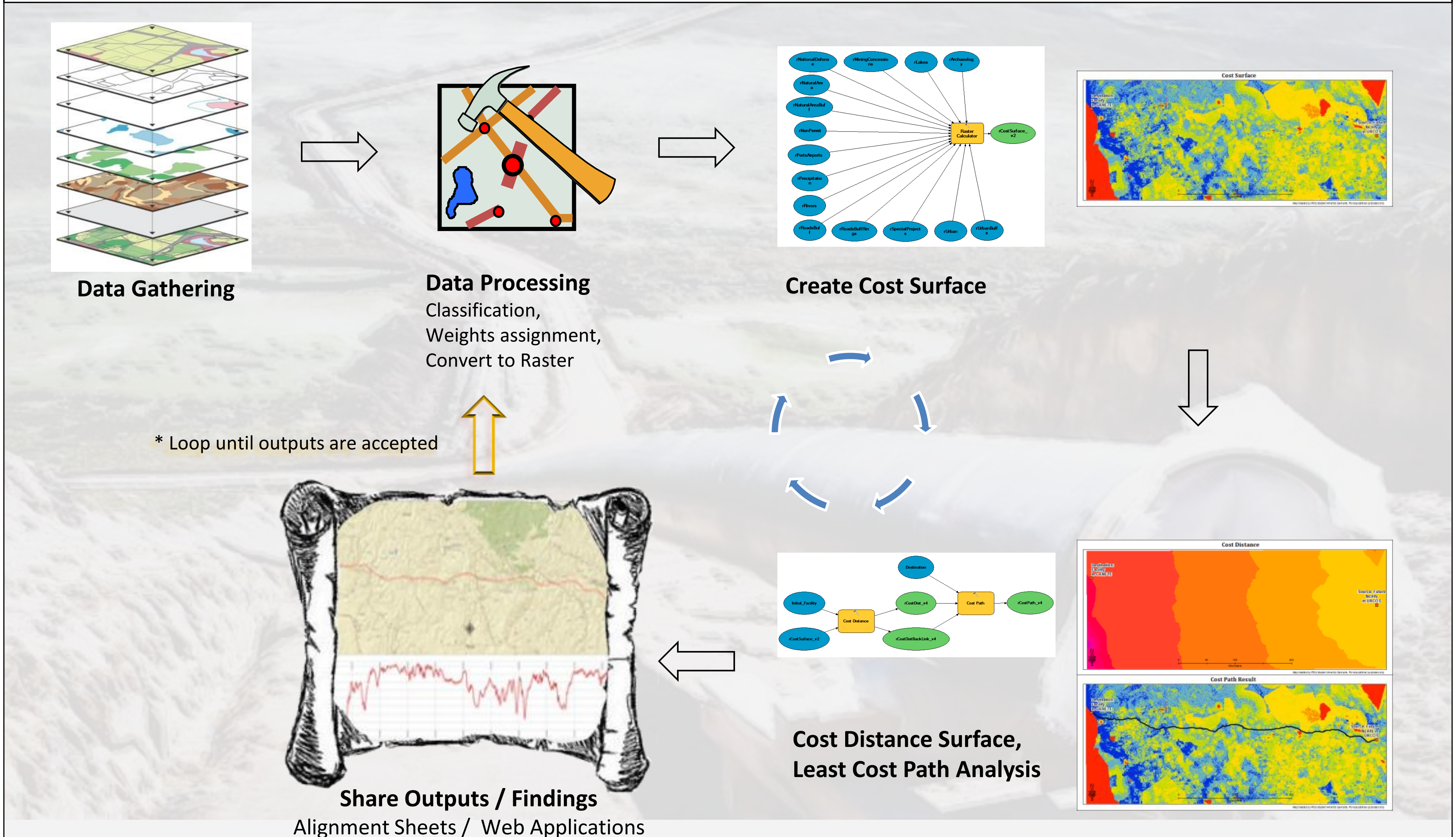
Data Analysis

Data Required

Based on the criteria the information 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.



Methodology

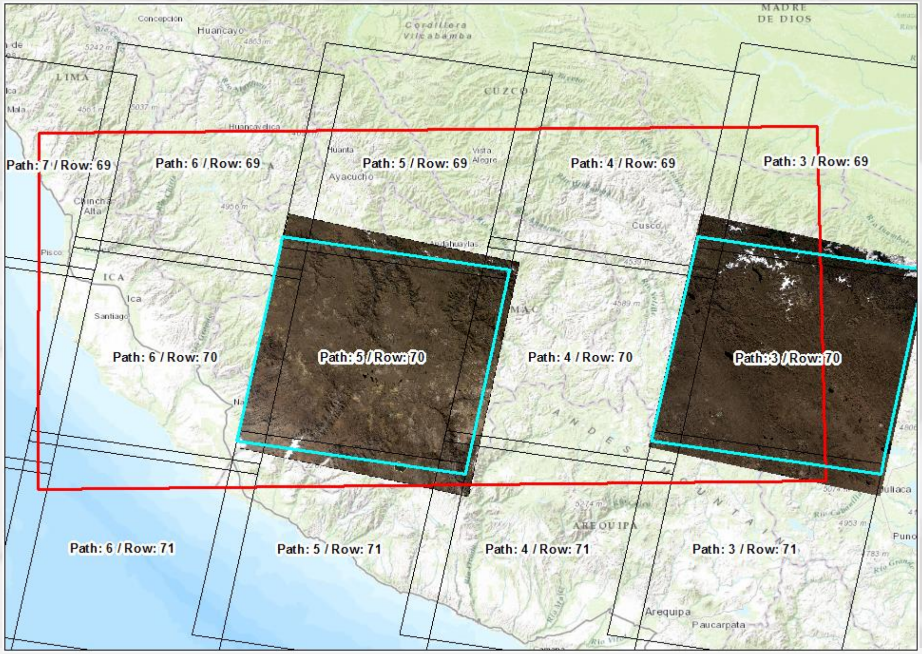


Data Processing (Data Classification)

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		

Data Processing (water bodies feature extraction)

- There are hundreds of water bodies in the Andes mountains not available in public spatial information.
- Identify water bodies (lakes, lagoons) in all of their forms (including ice areas) from Landsat 8 imagery (http://landsat.usgs.gov) in the area of interest.
- Extract water bodies polygon features using Object Based Classification on Landsat 8 imagery.



Data Processing (water bodies feature extraction)

CALCULATION OF INDEXES

NDVI
Normalized Difference Vegetation Index
(NIR – Red) / (NIR + Red)

Abs_NDVI
Absolute value of NDVI

MNDWI
Modified Normalized Difference Water Index
(Green-SWIR1)/ (Green+SWIR1)

Diff_SWIR
Difference of SWIR bands
SWIR1 – SWIR2

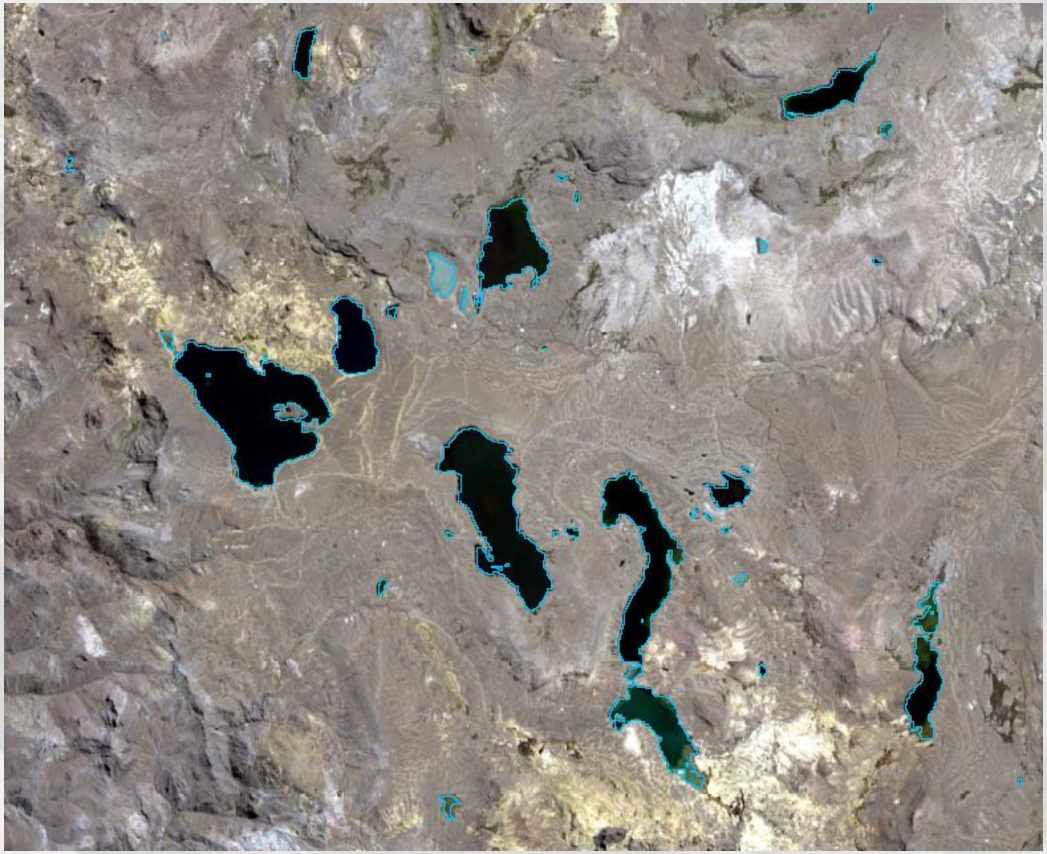
FEATURE EXTRACTION PROCESS

Classification
Water_PreClass
Abs_NDVI <= 1.5 and
SWIR1 <= 5600
Water
Diff_SWIR <=55 and
MNDWI >= 0.06

Merge Water Regions

Export Water Bodies to shapefile
(polygons)

Object Based Classification



Results: only 0.4% of classified pixels are not water, from 34,730 pixels classified as water only 154 pixels were NOT water.

Data Processing (Weights Assignment)

Each dataset is classified in categories and each category is assigned a weight (from 0 to 10). No-go areas are assigned a value of 100.

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 archaeological 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 overlaping	0			
Granted but not active	3		Overlaping with other Ro\	2			
Active	7		Overlaping with others	10			

Data Processing (Weights Assignment)

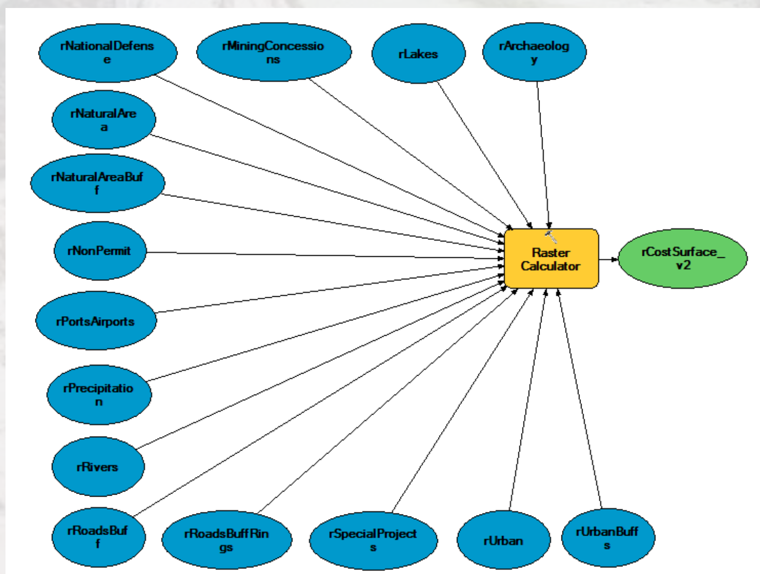
First each dataset gets an "importance factor" which is calculated by a direct comparison of each data set against all other datasets.

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		

Data Processing (Cost Surface)

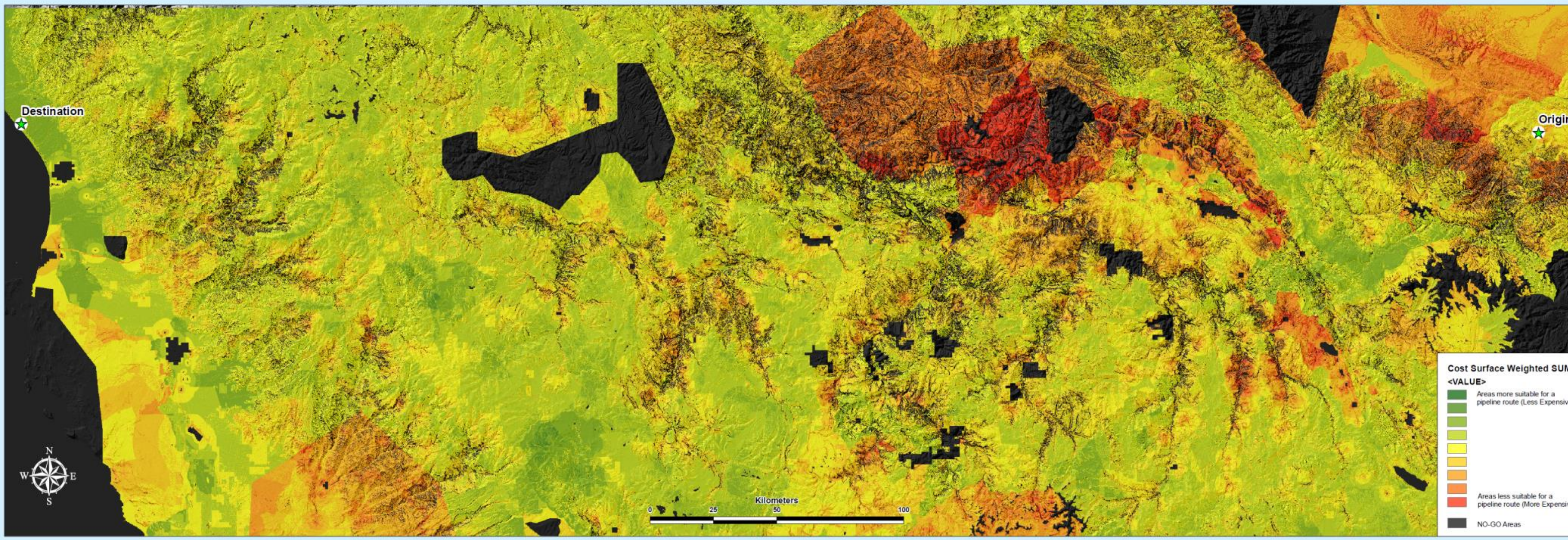
After each dataset (and sub categories) is assigned a weight value, converted to raster then a Cost Surface is calculated by a **Weighted SUM** using the “importance factor”.

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



Data Processing (Cost Surface)

Cost Surface



Areas more suitable (less expensive) for pipeline route

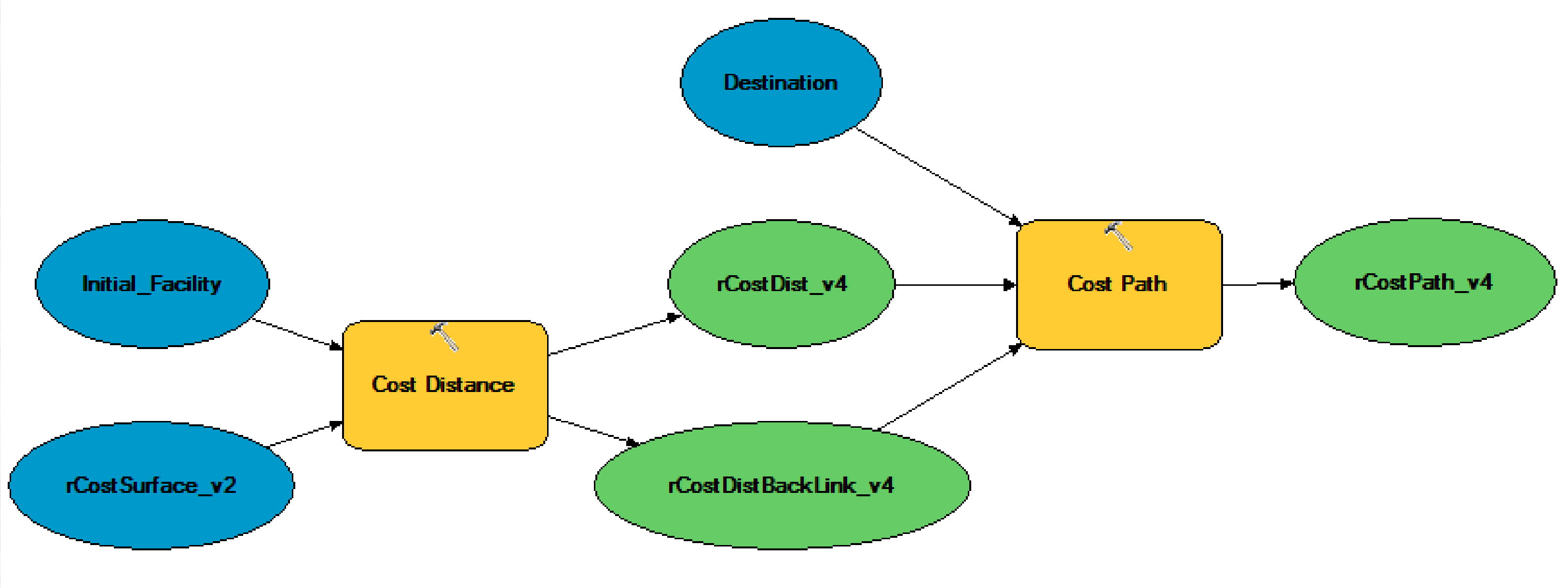
No-go areas

Areas less suitable (more expensive) for pipeline route

Data Processing (Cost Distance / Cost Path)

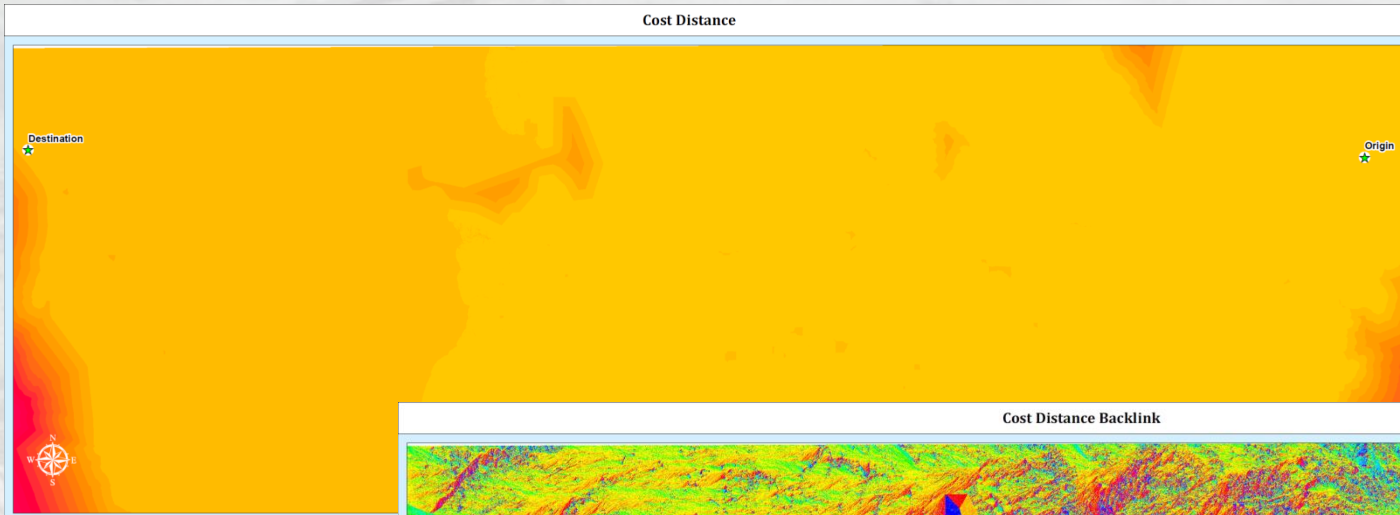
Using the Cost Distance Surface as input two geo processes take place to calculate the least cost path:

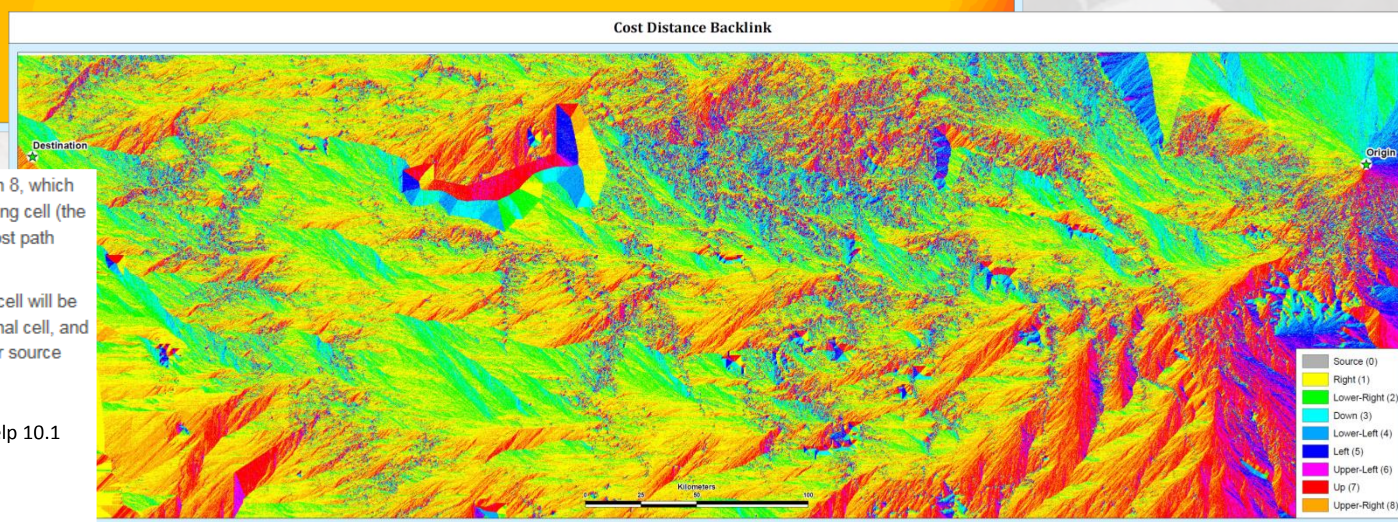
- Cost Distance (outputs: Cost Distance & Cost Distance Backlink) for an initial or source location.
- Cost Path (output: Least Cost Path)



Data Processing (Cost Distance)

Cost Distance & Cost Distance Backlink





The back-link raster contains values of 0 through 8, which define the direction or identify the next neighboring cell (the succeeding cell) along the least accumulative cost path from a cell to reach its least cost source.

If the path is to pass into the right neighbor, the cell will be assigned the value 1, 2 for the lower right diagonal cell, and continuing clockwise. The value 0 is reserved for source cells.

6	7	8
5	0	1
4	3	2

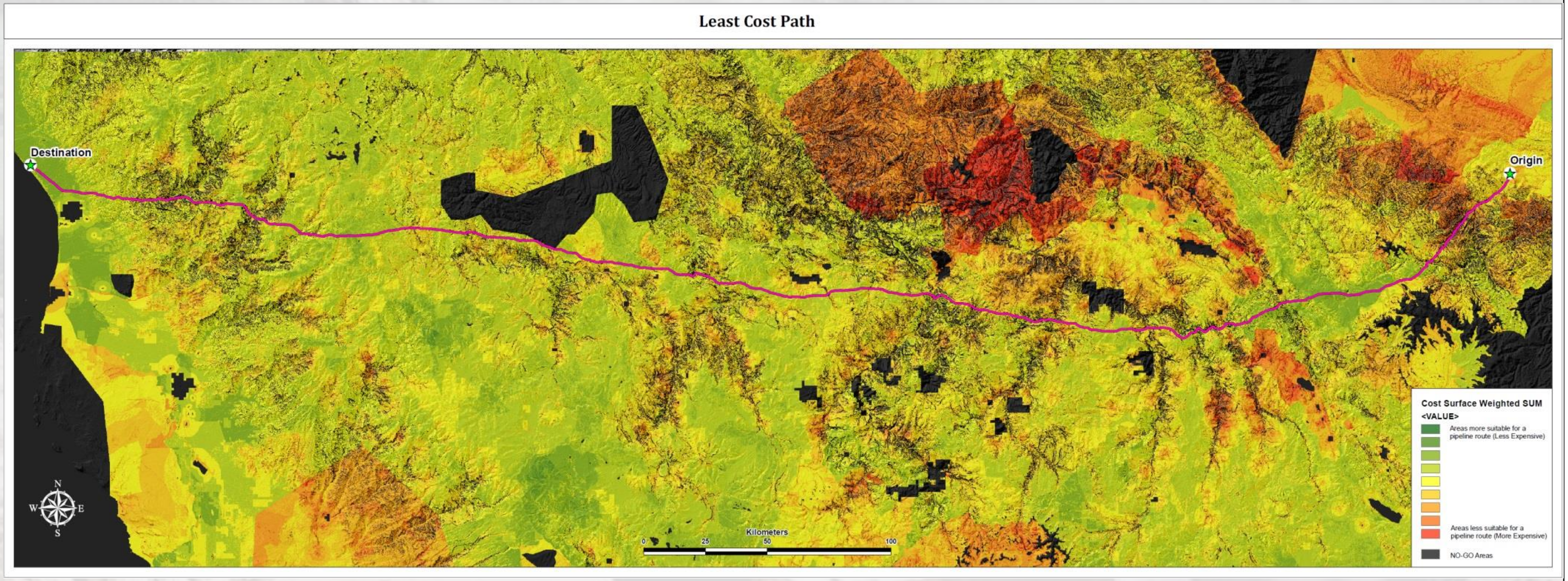
☐ Source cell

Back-link positions

ESRI ArcGIS Help 10.1

Preliminary Results and Products

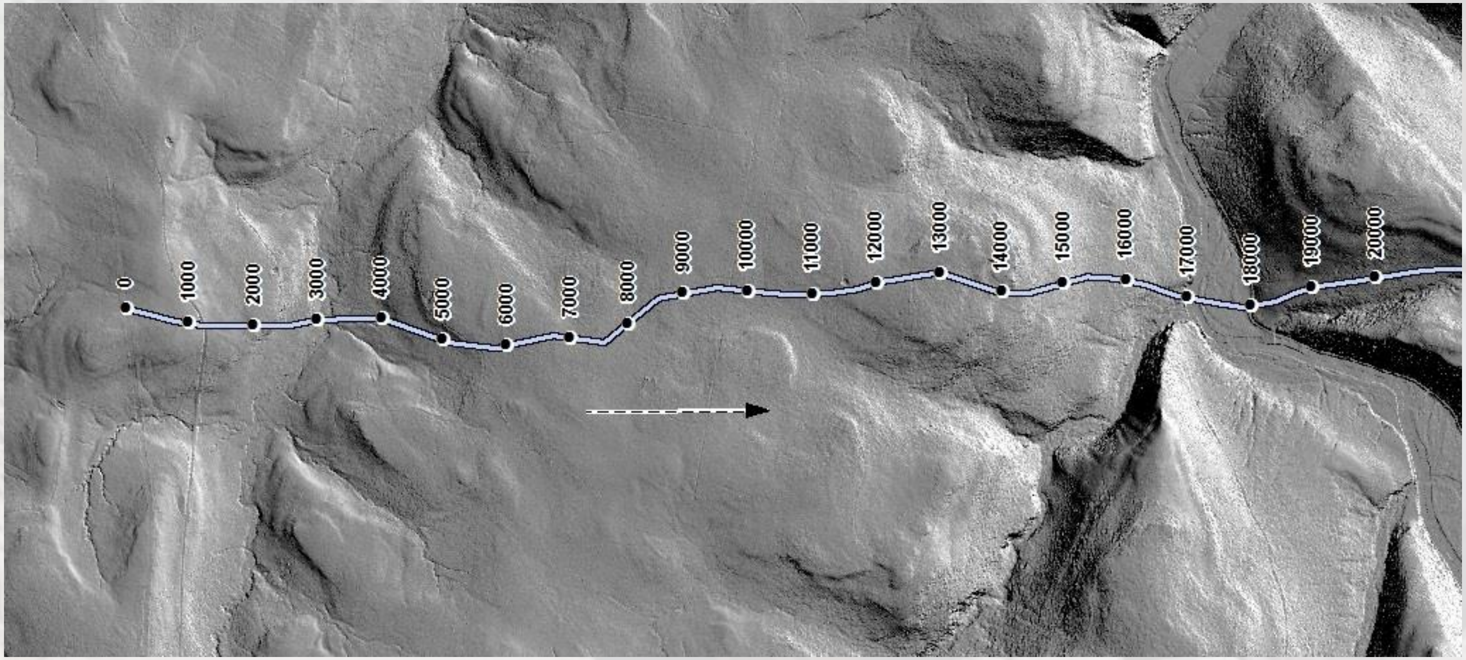
Least Cost Path



Preliminary Results and Products

- Least Cost Path is then converted from raster to a polyline.

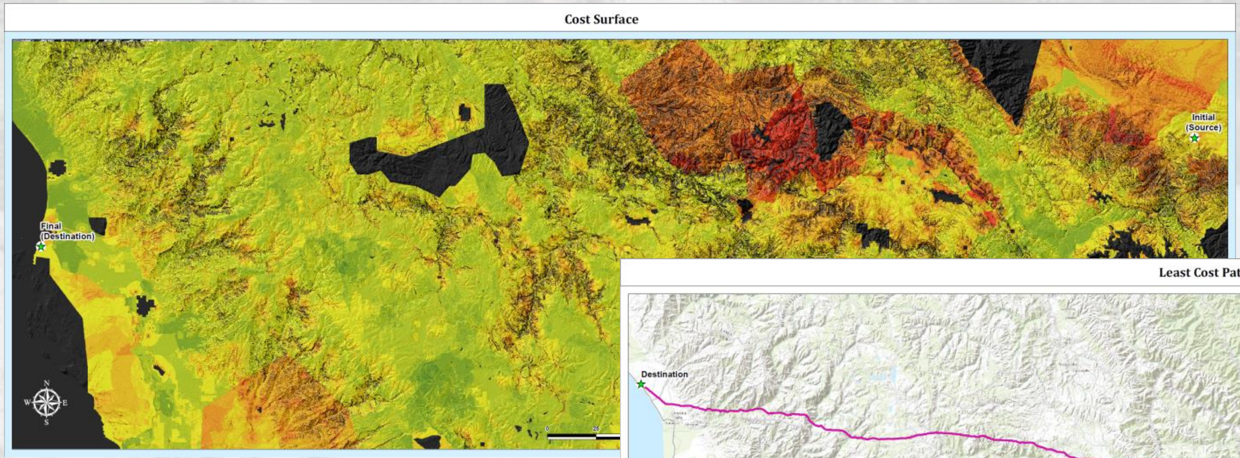
- The polyline is then converted to a "calibrated line" or Linear Referencing entity (XYZM Polyline), where Z values are gathered from the input 30m DEM and M values (3D distance) are calculated for each vertices.

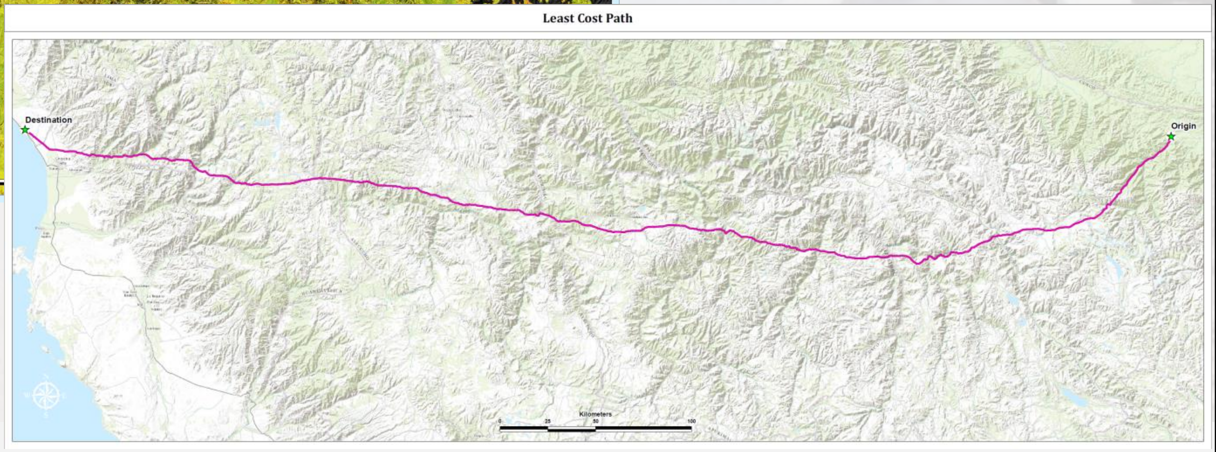


Preliminary Results and Products

Some preliminary attempts have been done as a “proof of concept” for this project, and Engineering department considers two main products for decision making about the pipeline route.

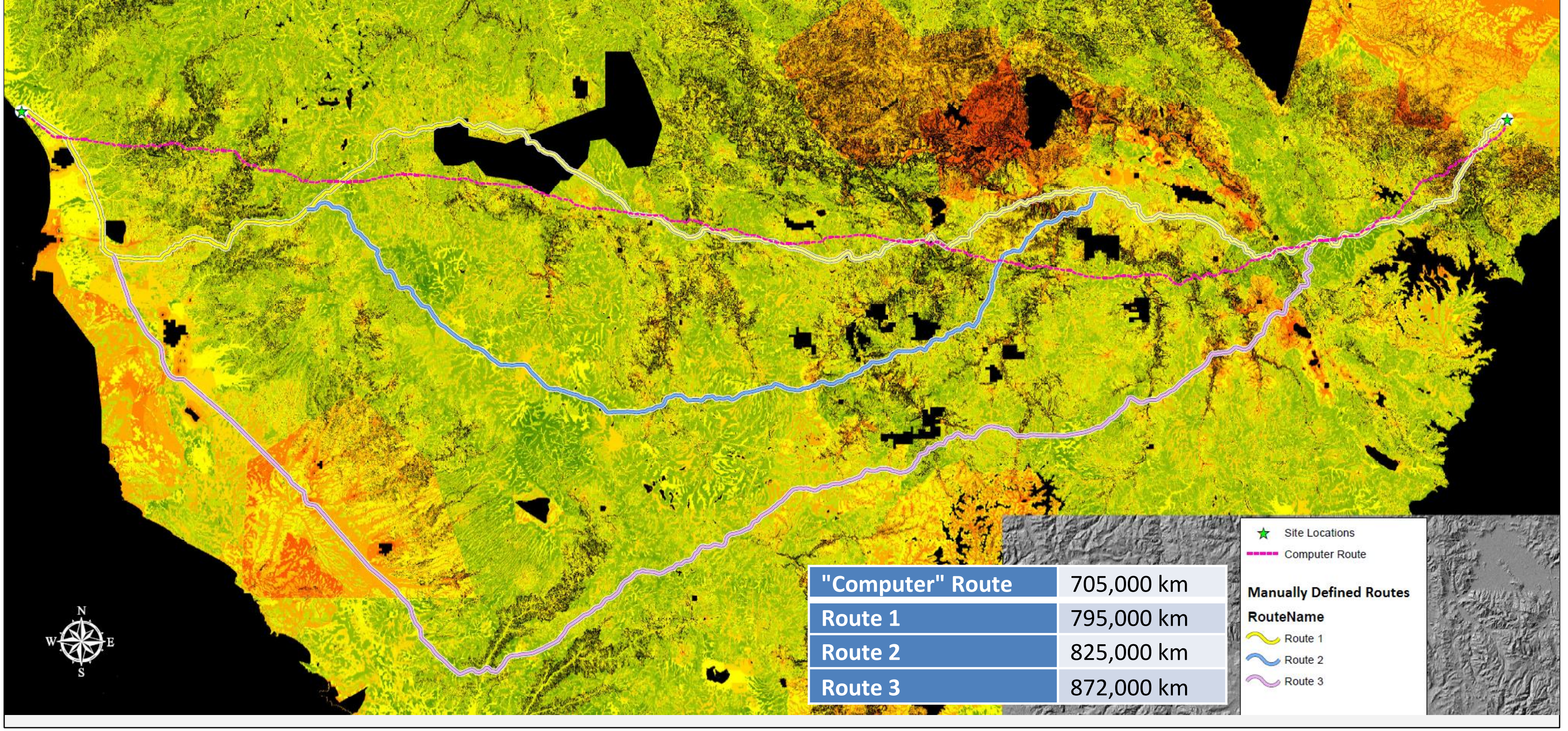
- Cost Surface
- Least Cost Path (XYZM Polyline) as a reference for pipeline route.





Preliminary Results and Products

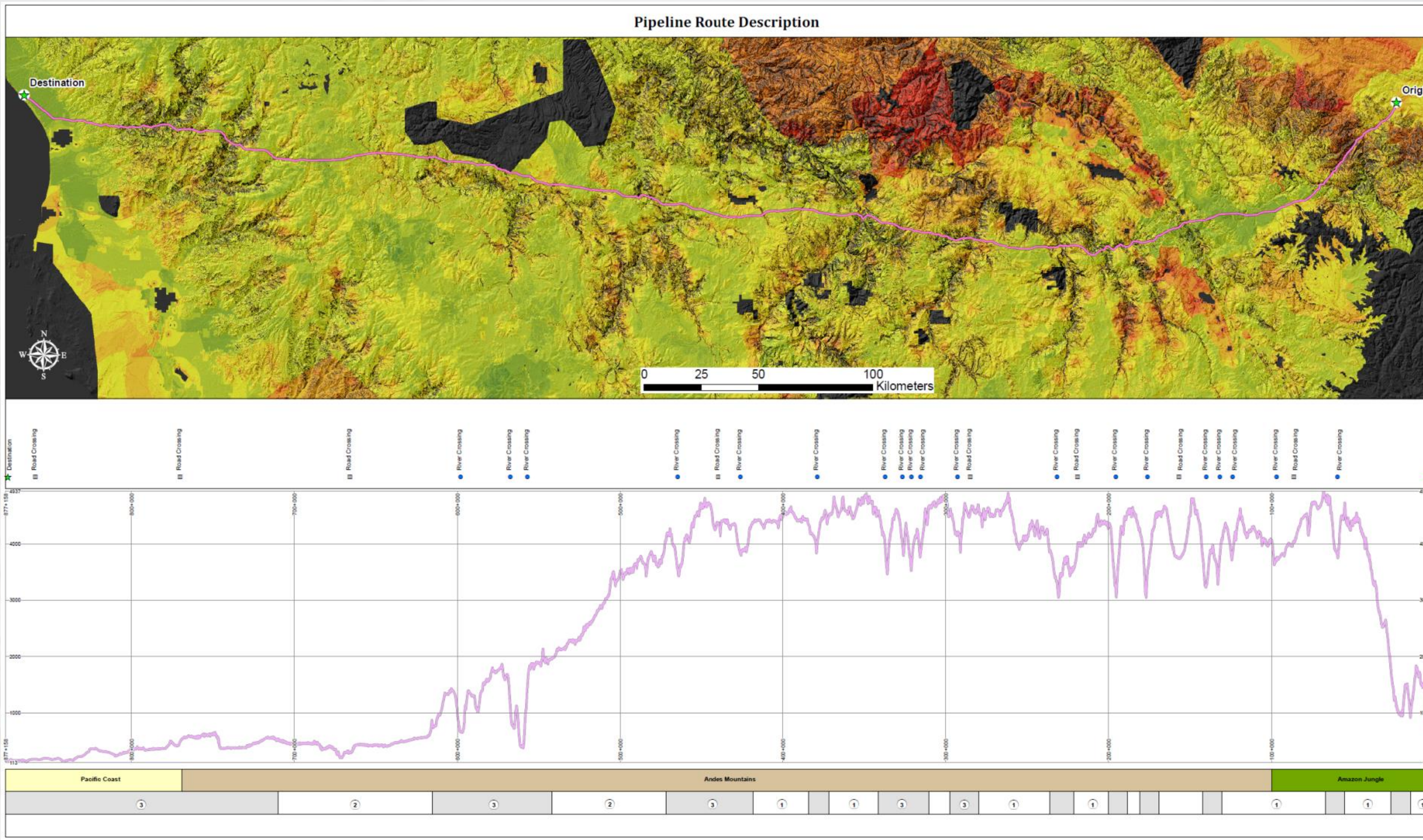
Comparison between computer calculated route versus manually defined routes.



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

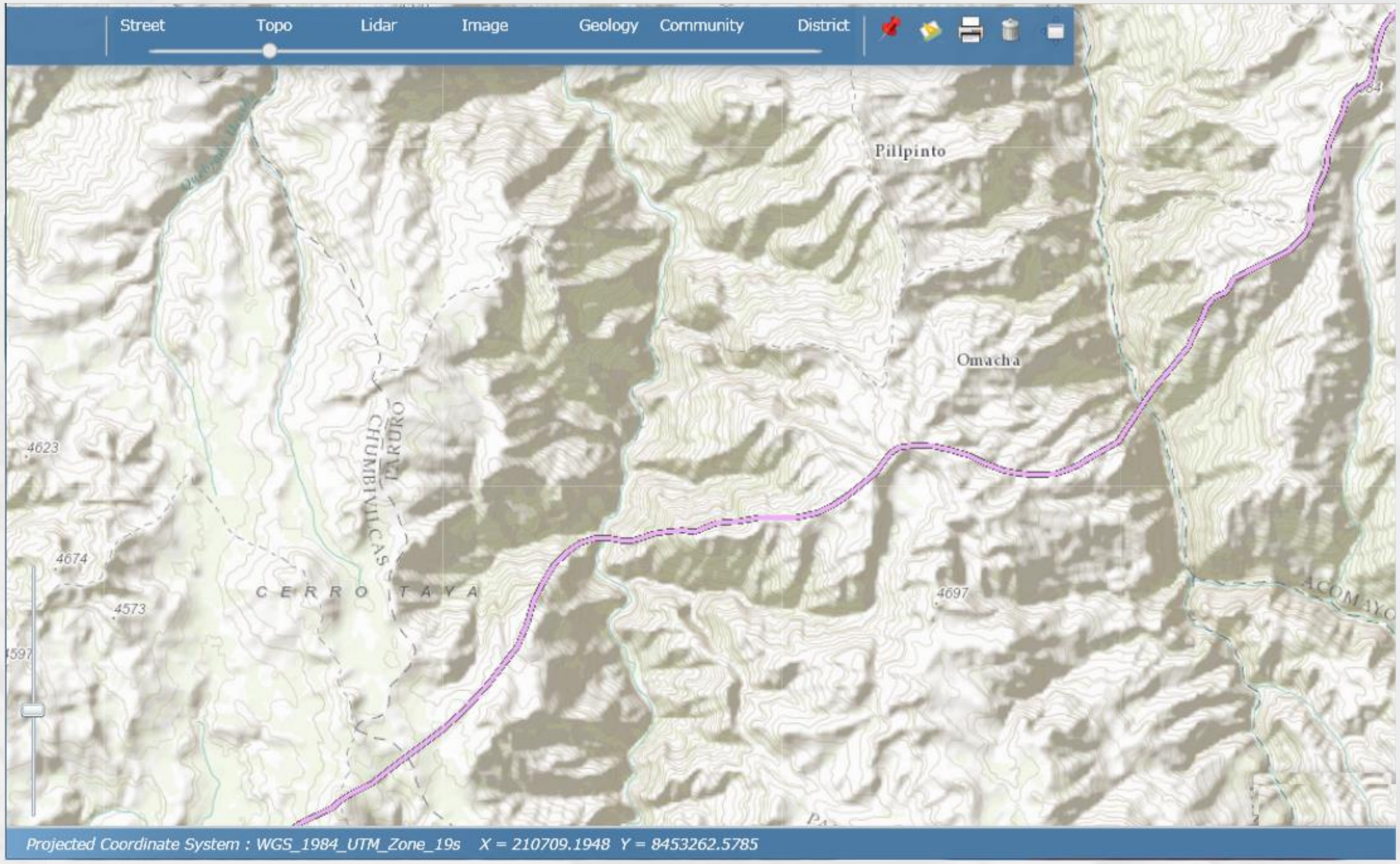
Data Sharing

Share results using Alignment Sheets, map reports that are effective to describe linear entities (pipelines).



Data Sharing

Share results using a GIS website.



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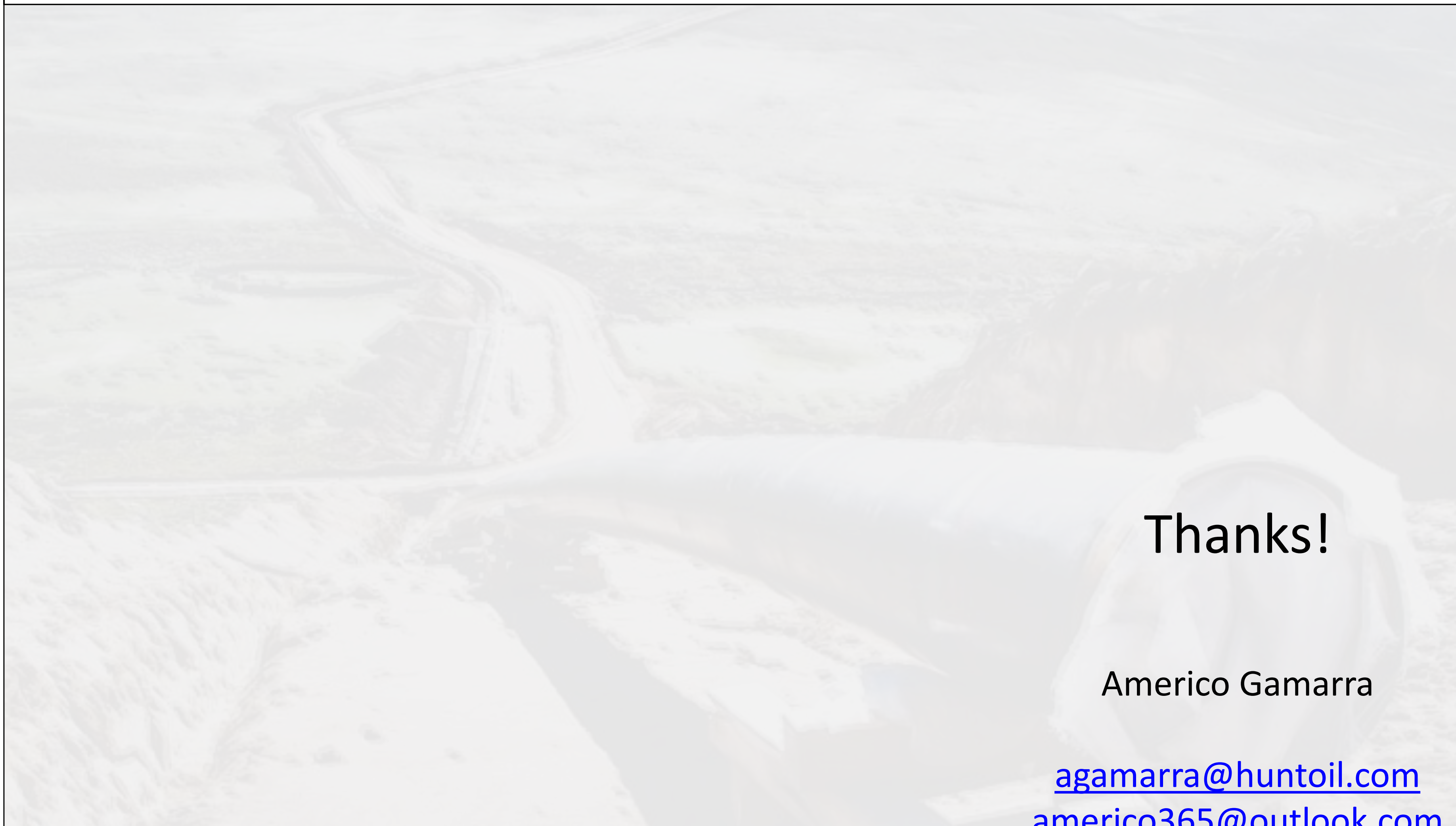
Questions?



Thanks!

Americo Gamarra

agamarra@huntoil.com
americo365@outlook.com