Applying Mathematical Model to Simplify the Procession of Pipeline Route Selection

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ABSTRACT

Now there are many pipelines to deliver liquid like water diversions in the world. Optimal route for pipeline transportation is a major concern for engineers, economists and decision makers. Pipeline route selection is governed by many factors such as the shortest distance between supply and demand points, constructability, affordability, environmental impacts and approachability. There are many methods developed for the pipeline route selection like Gestalt method, land suitability mapping techniques, geographic information systems (GIS), imaging technologies for pipeline mapping with the use of airborne lidar, etc. But these methods, though robust in translating physical constraints into feasible alternatives for route location, have their own pros and cons for applications, which are weak to incorporate the decision maker's preferences. This paper presents an easy approach for route selection with the angle of saving- energy and shortest distance. The method in this paper makes an attempt to establish a method for the route with minimum energy required with the aid of mathematics computing and GIS or the data coming from Google Earth. This method are demonstrated here through two different cases study of pipe route selection, the Los Angles aqua duct, the second Los Angles aqua duct in USA and water diversion from Palmer to Millbrook Reservoir in Australia. The calculated results are shown and analysed.

Key Words: Mathematical Model, Simplify, Pipeline Route Selection

INTRODUCTION

Nowadays, the number of pipelines installed for water transport has increased substantially in the last few decades (Um and Wright 1998). Optimal pipeline route selection is a major concern for the pubilc. For example, the Los Angeles Aqueduct aqueduct (Lee 1912) and the second in the USA, the South–North Water Transfer Project (SNWTP) in China (Berkoff 2003). They are due to most of the major centres of economic and social development are located in areas where water is not naturally found abundance. An extensive system of inter-basin water transfer schemes has been developed, by which water may be conveyed from areas of relative abundance to areas of need where water is relatively scare. This study focus on pipeline route selection on the principle of minimum energy.

There is a large literature dedicated to pipeline route selection. It includes several approaches, which take into account various aspects of the problem. Hopkins (Hopkins 1977) surveyed Gestalt method, which the lowest, the nominal scale is best represented. Then land suitability mapping can be performed at lots of different measurement scales. But this method requires the planner to be very familiar with the study area—a rare occurrence. Thus, the implicit nature of the method makes the results difficult to convey to the public and to the decision makers. More sophisticated methods had been discussed in Hopkins's following research. But the results were uncertain with the main cause of its mathematical incorrect to perform addition at the ordinal scale. Land suitability mapping techniques and geographic information systems (GIS) have been thoroughly discussed by P Jankowski and L Richard (Jankowski 1995). Land suitability mapping techniques were developed to allow planners to use various physical criteria for facility site selection. With the advent of GIS, land suitability mapping was automated, making the process quicker and more responsive to planners' needs. Land suitability mapping techniques and geographic information systems (GIS) have been used in the last decade to assist planners in route selection problems. But these techniques, though robust in translating physical constraints into feasible alternatives for route location, are weak in incorporating the decision maker's preferences, and, hence, are of limited use for decision support.

C. Vincent Tao (Tao and Hu 2002) addressed the use of airborne lidar and imaging technology for pipeline mapping. Airborne lidar is an aircraft-mounted laser system designed to measure the 3-D coordinates of Earth's surface. The lidar can acquire terrain surface data with high accuracy and provide rapid 3-D data collection of long linear objects such as pipeline corridors, roads, railway tracks, waterways, coastal or power lines. But lidar systems have a narrower swath in comparison to optical sensors; they are more cost-effective in capturing information needed for above applications. Besides, the accuracy of lidar depends on the specific configuration of a lidar system. The inertial measurement unites (IMU) accuracy varies somewhat according to the flying height. These require engineers to take a lot of time to select data, master lidar, lidar DEM derivatives and how to make sure the terrain parameters, which is not convenient for just crude design the optimal pipeline route. In addition, the cost of the lidar data is delicate as the variety of data products that can be produced. Each lidar data vendor has different prices. More, the numerous configurations that are available with each lidar system add difficulty to the generalized quote price. For example, the typical lidar corridor surveys can range in price from US$125 to US$500 per linear kilometre (Tao and Hu 2002), which is expensive for general pipeline route selection.

William E. Roper and Subijoy Dutta provided using remote sensing and GIS systems (Roper and Dutta 2005). But pipeline often cover thousands of miles and are located in remote area that are difficult or expensive to monitor. Due to sensor developments include a new generation of high-resolution commercial satellites that will provide unique levels of accuracy in spatial, spectral and temporal attributes, William E. Roper and Subijoy Dutta demonstrated pipeline selection using remote sensing and data visualization management systems (Roper and Dutta 2006). However, Applying geospatial technologies to the electric utility sector can be slowed or impeded by many factors which the need for improved methods and authorities for better data sharing across institutional boundaries are included. The developers and user communities need to communicate better and overcome some significant disciplinary differences. So this is the challenge for technical issues in the multi-sensor data fusion area to be overcome. Besides, to share information in a seamless fashion is required for parties at great distances. The shared information needs to be interactive with local data allowing it to be used in creating new integrated products tailored to the situation (Roper and Dutta 2006). For pipeline selection, it become more reliant on geospatial data today. Nevertheless the rapid and cost-affordable acquisition of terrain data along the pipeline corridor becomes increasingly critical. The pipeline engineers are under increasing pressure to search or produce accurate maps of pipeline routes.

The factors that lead to pipeline route selection are both objective and subjective. For example, for cross-country petroleum pipeline route selection, it is governed by the following goals: establish the shortest possible route connecting originating, intermediate and terminal locations (Dey 2002). A well selected route is to save money when it comes to the time and labour needed to acquire that route, as well as in the cost of the actual construction and materials for building the pipeline. Many factors effect to select the optimal route, such as environmental sensitivity, technical considerations, physical suitability, cultural heritage/significance, social impacts, existing land use, and land marked for future development (APIA 2009). As a complex process, the elements involved can be grouped into two main categories: primary and secondary. Primary factors include the location of the host (start) and destination (end) of the pipeline, and installation parameters that may affect route geometry. Secondary factors include bathymetry, seafloor character, sub seabed geology, geohazards, bio-environmental issues and existing infrastructure. The final factor, which is distinct from these two groups, is cost. Shorter pipelines cost less. Therefore the challenge for any pipeline route selection team is to find the shortest route while conforming to the requirements set out by the primary and secondary factors (Tootill, Vandenbossche et al. 2004). Transportation of energy resources is a major concern for the public and the pipeline industry (Nussbaum 2012). This study establishes a method for the route with minimum energy required with the aid of mathematics computing and the data coming from Google earth. The purpose is to present an approach which is an easier way which provides reference for an optimal choice of sites and routes.

METHODOLOGY

This section adopts a mathematical model to optimise pipeline route selection. The processions of analysis are in the listing. The series of equations as follows are developed to help determine the energy required to pump water from one location to another.

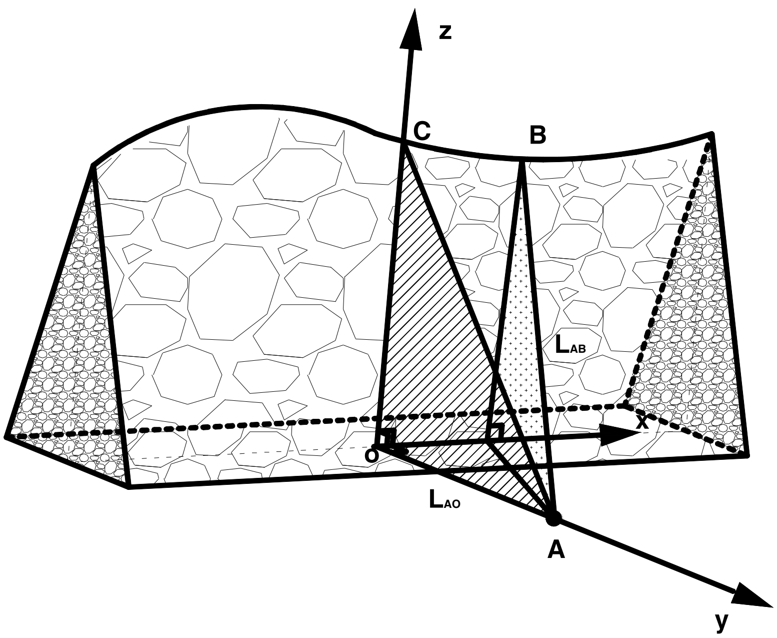


Figure 1. Basic diagram of an efficient pumping route from location A to B

In figure 1, A is taken as the starting location and B is taken to be the location of the point on the mountains or hills which the pipeline passes. To pump water from A to B, the following equations are applied.

$$(z+\frac{p}{\rho g}+\frac{V^2}{2g})_A+h_{pump}=(z+\frac{p}{\rho g}+\frac{V^2}{2g})_B+h_{loss} \quad \textbf{(1)}$$

If $z_A = 0$, $z_B = z(x)$, $p_A = p_B = 0$, $v_A = v_B = 0$. The equation 1 can be simplified to equation 2.

$$h_{pump}=z_B+h_{loss} \quad \textbf{(2)}$$

where h_{pump} is then calculated in equation 3, Hydraulic pump calculation

$$h_{pump} = z_B + \alpha L_{AB} \quad \textbf{(3)}$$

where L_{AB} and α being given in Equation 4 and 5

$$L_{AB} = \sqrt{L_{AO}^2 + x^2 + {z_B}^2} \quad \textbf{(4)}$$

$$\alpha = f\frac{V^2}{2gD} \quad \textbf{(5)}$$

If the energy is at a minimum by the change in the pipe outlet at location B, then

$$\frac{dz_B}{dx} + \alpha\frac{dL_{AB}}{dx} = \frac{dz_B}{dx} + \frac{\alpha}{2}\frac{2x + 2z_B z_B'}{\sqrt{L_{AO}^2 + x^2 + z_B^2}} = 0 \quad \textbf{(6)}$$

The minimum energy consumption meets equations 6's condition, then equation 7 can be derived.

$$\frac{\alpha x}{\sqrt{L_{AO}^2 + x^2 + z_B^2}} = -(1 + \frac{\alpha z_B}{\sqrt{L_{AO}^2 + x^2 + z_B^2}})\frac{dz_B}{dx} \quad \textbf{(7)}$$

Equation 7 can be solved to find h_{pump} giving the smallest amount of energy needed to divert the water, thus the best route to relocate water from storage in a Reservoir to a distribution centre. dz_B is the slope of the catchment boundary between the two locations and L_{AO} is the distance between 2 points in the y direction if height is not considered. Both of these values can easily be obtained from current topography maps. Then equation 7 can be re-written as following.

$$H_{pump} = -(1 + \frac{\alpha z_B}{\sqrt{L_{AO}^2 + x^2 + z_B^2}})\frac{dz_B}{dx} \quad \textbf{(8)}$$

However in this equation 'α' is a value determined by the dimensions of the pipe; including diameter and the friction factor due to the pipe surface. If we assume that all possible pipe diversions will use the same piping with the same diameter, friction factor and constructed from the same material, then 'α' can be taken as a constant, therefore we can make it equal to one. When 'α' is said to be a constant, equation 9 is then got.

$$H_{pump} = -(1 + \frac{z_B}{\sqrt{L_{AO}^2 + x^2 + z_B^2}})\frac{dz_B}{dx} \quad \textbf{(9)}$$

Equation 9 can be solved to get h_{pump} giving the smallest amount of energy needed to divert the water, which means the best route to relocate water from storage to a distribution centre.

In order to indentify that the equations produce the most energy-saving path of diversion, the equations have been applied to two existing pipelines.

CASE STUDIES

Case Study One. The Los Angeles Aqueduct System and the Second, USA

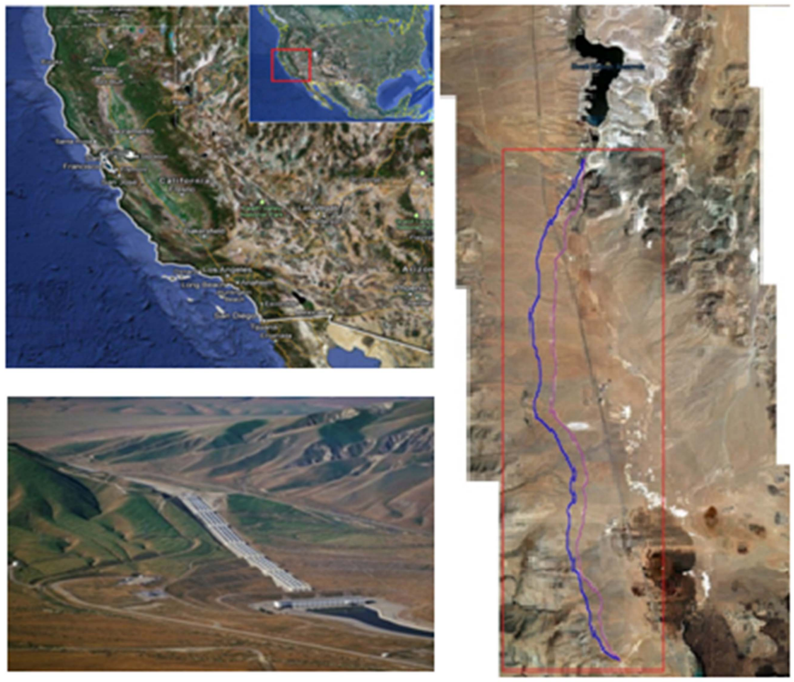
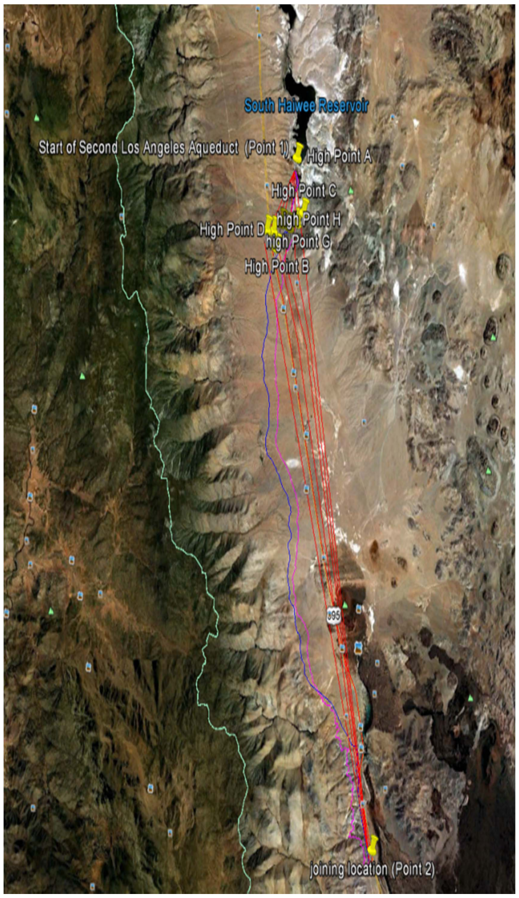


Figure 2 the Los Angeles Aqueduct System (Purple Line) and the Second (Blue Line), USA

The Los Angeles Aqueduct system (USA) comprising the Los Angeles Aqueduct (Owens Valley aqueduct) and the Second Los Angeles Aqueduct is a water conveyance system operated by the Los Angeles Department of Water and Power (LADWP 2012). The system delivers water from the Owens River in the Eastern Sierra Nevada Mountains to Los Angeles, California. The aqueduct's water provided developers with the resources to quickly develop the San Fernando Valley and Los Angeles during World War II. The challenge to supply water to Los Angeles continued to press. Because the capacity of the Los Angeles Aqueduct was limited, the City was unable to take its full entitlement from the Mono Basin. The California State Water Rights Board urged Los Angeles to take steps to develop its full entitlement, or risk that the water might be granted to others. To increase the Aqueduct capacity, a second aqueduct was built from Haiwee Reservoir in Southern Inyo County to Los Angeles. The second Los Angeles Aqueduct which was completed by 1970 starts at the Haiwee Reservoir, just south of Owens Lake, running roughly parallel to the first aqueduct. Unlike the original, it does not operate solely via gravity and requires pumping to operate. It carries water 137 miles (220 km) and merges with the original aqueduct near the Cascades, visibly located on the east side of the Golden State Freeway near the junction of State Route 14, which makes Los

Angeles have become the nation's second largest city as it is the second reliable water supply. The case in this study chooses from South Haiwee Reservoir which is the start of Second Los Angeles Aqueduct (Point 1) to the jointing location of First and Second Los Angeles Aqueduct (Point 2) (See figure 2).



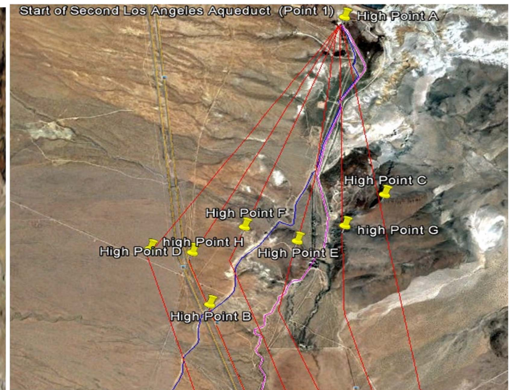


Figure 4. North of aqueduct system

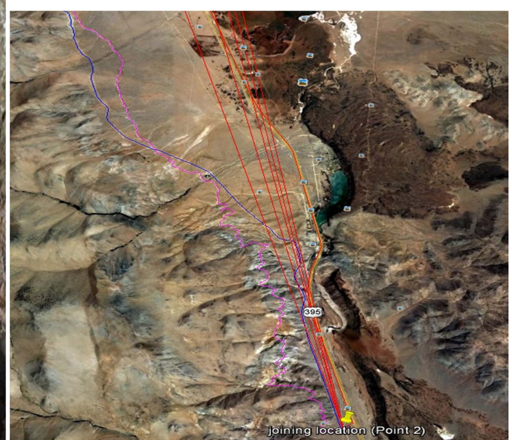


Figure 3. Whole aqueduct system

Figure 5. South of aqueduct system

Table 1. Location of High Points along Los Angeles Aqueduct Diversion Paths

Diversion path	Path information	Latitude (degrees)	Longitude (degrees)	Altitude (m)
A	Los Angeles Aqueduct	36.13534	-117.95352	1126
B	Second Los Angeles Aqueduct	36.10464	-117.96819	1142
C	Straight path (point 1 to point 2)	36.11623	-117.94902	1254
D	Following route 395 (highway)	36.11022	-117.97001	1169
E	Alternative 1	36.11144	-117.95863	1159
F	Alternative 2	36.11294	-117.96439	1150
G	Alternative 3	36.11305	-117.95340	1195
H	Alternative 4	36.11059	-117.97451	1196

For the equations, h_{pump} is energy needed, α is a constant for all pipe diversions it can be taken as 1. By employing equation 9, the different diversions are compared to the current pipe work (Figures 3-5), where varying value z_B is different between point A and B; L_{AO} is the perpendicular distance from A to the highest point as the crow flies; x is the distance in x direction from A to highest point. Table 1 and 2 show different points chosen to calculate where the most energy is saved.

Table 2. Summary of Los Angeles Aqueduct Diversion Path energy calculations

Diversion Route	Path information	x (m)	L_{AO} (m)	z_b (m)	$\boxed{\sqrt{L_{AO}^2 + x^2 + z_B^2}}$ (m)	h_{pump}
A	Aqueduct 1	0.43	-2135516	0	2135516	0.00000
B	Aqueduct 2	-2101	-2136677	15	2136678	0.00711
C	Straight path (point 1 to point 2)	-231	-2136813	127	2136813	0.55101
D	Following route 395	-20821	-2136277	42	2136278	0.02017
E	Alternative 1	-1141	-2136686	32	2136686	0.02805
F	Alternative 2	-15521	-2136356	23	2136357	0.01482
G	Alternative 3	-6761	-2136813	68	2136813	0.10058
H	Alternative 4	-2429	-2136065	69	2136066	0.02841

Note: If units are not mentioned then they are a dimensionless quantity.

From Table 2, it can be seen that the two most efficient diversion paths are the two existing pipelines—Aqueduct 1 and 2. For the route A, h_{pump} value is zero, which coincides the fact that the existing Aqueduct 1 is gravity operated without energy required. The h_{pump} value in route B is the second smallest which is another coincidence with the other existing Aqueduct 2. Meanwhile, the third smallest h_{pump} value can be found in route D, where is a current freeway route 395. What is meant by this is that this calculation does not only suitable for water diversion, but also for other route selection. This successful application of equation 9 to these existing pipelines proves that the proposed calculation method can be used to determine the optimum diversion route.

Case Study Two. Water Diversion from Mannum to Millbrook Reservoir

The Mannum-Adelaide pipeline constructed in 1955 was the major pipeline to divert water from the River Murray, Australia (SA Water 2012). Adelaide sources 30% of its usable water from the River Murray during abundant wet periods and as much as 90% during times of drought (SA Water 2012), making this pipeline a major lifeline for Adelaide. The Latitude, Longitude and Altitude of the starting location of the existing Pipeline at Mannum was found to be -34.91 degrees, 139.30 degrees and 36 m respectively, which are -3965325.888 m, 3410718.337 m and 36 m in Cartesian coordinates.

Figure 6 shows an aerial view of the area including the highlighted existing pipeline. The red lines represent the various diversion paths chosen with the white line showing the existing Mannum-Adelaide pipeline which all travel over the Mt Lofty ranges; these paths are chosen at 1.8 km intervals along the range as shown in figure 6. It was decided that once the energy values demonstrate an increasing pattern, due to the distance from the starting point no more diversion routes would be created in that direction. The high point on each of these paths was determined with the latitude, longitude and altitudes shown in table 3, these high points are also shown on figure 6.

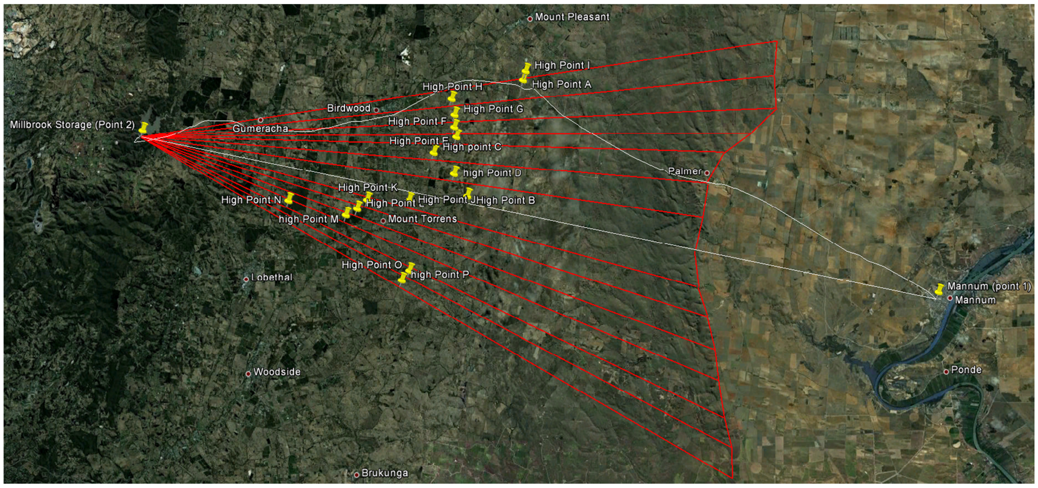


Figure 6. Diversion Paths and Their Respective High Points

Table 3. Location of High Points Along Mannum-Adelaide Diversion Paths

Diversion path	Path information	Latitude (degrees)	Longitude (degrees)	Altitude (m)
A	Existing Pipe	-34.81	139.04	466
B	Straight from A to B	-34.87	139.01	509
C	Straight From Mountain range to B	-34.85	138.99	511
D	Midpoint Between A and B	-34.86	139.00	510
E	1.8 km North along Mt range	-34.84	139.00	520
F	3.6 km North along Mt range	-34.83	139.00	532
G	5.4 km North along Mt range	-34.83	139.00	541
H	7.2 km North along Mt range	-34.82	139.00	498
I	9.0 km North along Mt range	-34.80	139.05	472
J	1.8 km South along Mt range	-34.87	138.97	517
K	3.6 km South along Mt range	-34.87	138.95	541
L	5.4 km South along Mt range	-34.87	138.94	583
M	7.2 km South along Mt range	-34.88	138.93	538
N	9.0 km South along Mt range	-34.87	138.90	541
O	14.2 km south along Mt range	-34.90	138.97	536
P	16.0 km south Along Mt range	-34.91	138.97	540

These locations are then changed to Cartesian coordinates and equation 9 is applied to determine h_{pump} for each diversion case allowing the most energy efficient path to be observed, these results are shown in table 4. The h_{pump} that is calculated only allows a comparison to be made between diversion paths and is a dimensionless quantity. Equation 9 could be applied to determine the energy required to pump the water from Mannum to Millbrook Reservoir if an appropriate type of piping was chosen.

Table 4. Summary of Mannum-Adelaide Diversion Path Energy Calculations

Diversion Route	**Path information**	**x (m)**	**L_{AO} (m)**	**z_b (m)**	$\boxed{\sqrt{L_{AO}^2 + x^2 + z_B^2}}$ **(m)**	**h_{pump}**
A	Existing Pipe from 1 to 2	-10713	-22130	430	24590	0.0408
B	Straight path from 1 to 2	-15391	-21697	473	26606	0.0313
C	0.0 Km along Mountain Range	-15629	-23911	475	28570	0.0309
D	Midpoint Between A and B	-15510	-22804	474	27583	0.0311
E	1.8 km North along Mt range	-14550	-23637	484	27765	0.0338
F	3.6 km North along Mt range	-14070	-24056	496	27873	0.0359
G	5.4 km North along Mt range	-14070	-24056	505	27873	0.0365
H	7.2 km North along Mt range	-13590	-24473	462	279970	0.0346
I	9.0 km North along Mt range	-9634	-21856	436	238890	0.0461
J	5.4 km South along Mt range	-17788	-24454	481	302430	0.0275
K	7.2 km South along Mt range	-18988	-25832	505	32064	0.0270
L	9.0 km South along Mt range	-19587	-26520	547	329740	0.0284
M	10.8 km South along Mt range	-20667	-26791	502	338400	0.0246
N	12.6 km South along Mt range	-21988	-29274	505	36616	**0.0233**
O	14.2 km South along Mt range	-19229	-23200	500	301370	0.0264

Note: If units are not started then they are a dimensionless quantity.

From table 4 it can be seen that the most efficient diversion path is case N, which the route that runs through the mountain range 12.6 km south of the existing pipeline. However the existing pipelines route has one of the largest h_{pump} values compared to the other diversion routes. This may be attributed to several reasons which may or may not include:

(1) Saving energy was not concerned during the pipelines construction due to urgent need of the residents of Adelaide and south west South Australia

(2) It may have been diverted this direction for environmental concerns such as national parks or endangered species

(3) The pipeline may have needed to be diverted around private property

(4) A lack of energy saving theories may have been present at the time of the pipelines design

There would be many more reasons which were not listed here but due to the long period of time that has elapsed since the pipelines constructed and the lack of computers during its design it makes the acquisition of the original pipelines plan almost impossible. Even though the analysis has shown that the existing pipeline is not the optimum diversion route, the calculation result provides an additional idea for the pipeline route selection, which may lead to future areas of research using these findings as a starting point.

DISCUSSION

In this paper, numerical modelling are analysed and compared to case study results. This mathematical model can be applied to simplify the procession of pipeline route selection. Yet, because pipeline route selection is relatively complicated decision process, which refers to economic, environmental and social details etc, this model can assist in the selection process in the aspect of saving energy. In addition, more studies will be done around this mathematical model, such as apply this model to GIS or others, which will simply the programming process to get the optimal pipeline route more quickly.

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