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Constraint Mapping for Avoiding Adverse Effects of Development: The Application to the Moomba to Stony Point Pipeline and Its Aftermath

Bryan R Jenkins

University of Adelaide, Adelaide 5005, Australia

Corresponding Author Email: bryan.jenkins.au@gmail.com

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ABSTRACT

Avoidance of impacts on areas of environmental significance is a desired outcome of environmental planning. This paper describes the process of constraint mapping that was used in the route selection for the Moomba to Stony Point hydrocarbon liquids pipeline in South Australia. The Flinders Ranges were on the direct line between Moomba and Stony Point so alternative alignments to the west and east of the ranges were considered as well as alternative crossings of the ranges for eastern alignments. Constraint mapping provided an effective tool for comparing the alignment alternatives and for identifying areas requiring more detailed impact evaluation. The aftermath of route selection was based on a major review of environmental impacts undertaken 25 years after construction and annual reporting of environmental incidents. Analysis of the aftermath confirms many of the considerations used in constraint mapping. It indicated that revegetation over the buried pipeline had occurred and that erosion at creek crossings was the major operational issue. The access road has more permanent impacts than the pipeline right-of-way while maintenance activities involving excavation and hydrocarbon release required effective management. With pipeline alignment selection through constraint mapping avoiding sensitive areas and effective management of operation and maintenance activities, the pipeline has been classified as 'low impact' by the regulator.

1. INTRODUCTION

This paper considers the contribution of constraint mapping to environmental impact assessment for the avoidance of adverse impacts of proposed developments. After the introduction, the case study of the application of constraint mapping for the route selection of the Moomba to Stony Point pipeline is presented. First the concept of constraint mapping is described. This is followed by a description of the steps involved in pipeline alignment identification and the preparation of the composite constraint map. This information provides the basis for comparative analysis of the alternative pipeline alignments and the selection of the preferred alignment.

The paper then considers the aftermath of the pipeline alignment decision. Aftermath analysis is an important basis for testing the value of constraint mapping [1]. The results of the environmental impact review that was undertaken 25 years after pipeline construction and annual reports of environmental incidences are compared with the information used as the basis for constraint mapping. This comparison is a key objective of the paper in examining impact prediction with actual outcomes.

The paper concludes by summarising the value of constraint mapping in facilitating the avoidance of adverse environmental impacts.

2. CONSTRAINT MAPPING FOR THE MOOMBA TO STONY POINT PIPELINE

2.1 The concept of constraint mapping

One of the most valuable tools that can be used in environmental planning is constraint map- ping. This concept was developed by Ian McHarg as set out in his book Design with Nature [2]. It consists of identifying both natural and social processes that need to be considered in designing proposed developments, in addition to the technical and economic considerations in project design.

At the plan development stage, the approach involves identifying the critical factors and ranking them from high to low in terms of their ecological or social value. For example, areas with vegetation associations of conservation significance would receive a high ranking. The factors for each value are mapped with areas of higher value shown with darker tone. Where there are multiple factors, the maps are superimposed. The areas which are of high ecological and social value are shown as dark tones while areas with lower social and ecological value are revealed by the lightest tone. This enables the siting of facilities to be undertaken to avoid areas of high ecological and social value.

2.2 Pipeline alignment identification

In selecting potential alignments for the Moomba to Stony Point pipeline, the composite constraint overlay technique was used. Environmental constraints were identified and for each environmental constraint, a transparent overlay was prepared indicating environmentally sensitive areas in grey tones [3]. Areas of greatest sensitivity were shaded in the darkest tone. By overlaying these maps of environmental constraints, it was possible to identify the areas of greatest potential for overall environmental impact by the darkest tone. Conversely, it was possible to identify areas of least impact as those with the lightest tone.

2.2.1 Steps in the preparation of the composite overlay

In the preparation of the composite overlay of environmental factors, the following tasks were undertaken:

(1) Selection of environmental constraints: potential environmental constraints were identified by an examination of the nature of the environment in the study area and the actions involved in pipeline construction and operation.

(2) Selection of an indicator of environmental suitability: for each environmental constraint, a factor was selected to indicate the relative sensitivity of potential impact in relation to each constraint. The categories for each indicator had to be capable of being ranked (i.e., expressed as on ordinal scale) and capable of being mapped across the study region.

(3) Assessment of weighting of environmental factors: based on the perceived importance of each factor, a relative weight was assigned to each value of the selected indicators. Darker shadings were given to show greater potential for adverse environmental impact.

(4) Preparation of factor maps: using different densities of grey shadings to reflect the selected weightings, individual factor maps were prepared for each indicator of environmental suitability. Certain fine-scale factors, such as faults or drainage channels had to be drawn as separate maps in black because of technical difficulties of showing them in grey. The conversion to grey was accomplished in the printing of the composite map.

2.2.2 Selection of environmental indicators

Environmental suitability or constraint maps were prepared for the following environmental factors:

(1) Vegetation associations: to avoid vegetation of conservation significance in clearing of the right-of-way;

(2) Significant fauna habitats: to avoid disturbances to fauna or their habitat because of right-of-way clearance and construction activity;

(3) Restorative capacity: to avoid areas of low restorative capacity in order to facilitate re- habilitation success based on rainfall reliability (ten percentile annual rainfall);

(4) Geomorphology: to avoid landforms of environmental significance in pipeline route selection;

(5) Drainage patterns: to avoid as much as possible the need for the pipeline alignment to cross creek channels and lake beds;

(6) Soil types: to avoid areas of high erosion potential in selecting the pipeline alignment;

(7) Seismic risk: although it is not considered a problem for modern steel pipelines, avoiding fault lines was included in constraint mapping;

(8) Land utilisation: to avoid town areas because of risk of third-party damage to the pipeline and unallocated Crown land because of vegetation fragility and being less able to regenerate;

(9) Land use planning zones: to avoid land of conservation and recreation significance, of high scenic value, or of scientific interest;

(10) Areas of conservation significance: to avoid national parks and conservation parks, as well as forest reserves, fossil reserves and sites of geological significance, and private conservation resorts;

(11) Archaeological and ethnographic sites: to avoid specific sites and areas of archaeological and ethnographic significance;

(12) Landscape values: to avoid areas of scenic value for the pipeline alignment and ancillary facilities; and

(13) Access availability: to avoid areas of restricted access (military facilities) and creating access to areas currently protected by their remoteness.

The approach used for vegetation associations is described as an example of an indicator scale. The clearing of the right-of-way had the potential for adversely affecting a narrow strip of vegetation. It was considered of greater environmental impact to clear areas containing vegetation of conservation significance, and of lower environmental impact to clear areas already disturbed or degraded. For ranking purposes, each vegetation association as defined by Environments of South Australia [4] in the study region was classified as follows:

(1) High conservation value: the environmental association contains rare or endangered plant alliances (as defined by [5]).

(2) Medium conservation value: the environmental associations contain species endemic to the region or at the extremes of their range (as described in [4]).

(3) Disturbed natural vegetation: the dominant environmental unit of the association con- tains vegetation affected by pastoral activity but with original composition and structure basically intact (as described in [4]).

(4) Degraded natural vegetation: the dominant environmental unit of the association contains native vegetation, but its basic structure has changed through intensive use, and recovery is likely to be a long process if possible at all.

The overlay produced from this information is shown in Figure 1. An overlay map for soil erodibility potential is also shown.

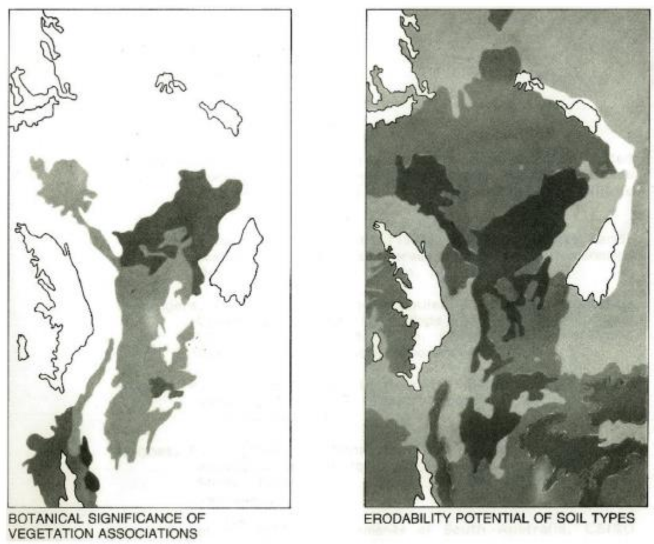

Figure 1. Constraint overlays for vegetation associations and erodibility of soil types [3]

2.2.3 Composite overlay

Table 1 displays the relative weight given to the indicator scales. The weights were reflected in the density of grey used to represent these considerations in the composite overlay. The weight represents a subjective assessment of relative importance designed to reflect impact potential and to provide visual contrast.

Table 1. Weights given to scales of environmental indicators

Environmental indicator	**Relative weight**					**Pantone**
	0	**1**	**2**	**3**	**4**	**scale**
VEGETATION ASSOCIATION						
High Conservation Value				*		404+400
Moderate Conservation Value			*			402+400
Disturbed Natural Vegetation		*				400
Degraded Natural Vegetation	*					Clear
SIGNIFICANT FAUNA HABITAT						
Known Habitat of Rare Species					*	406
General Area of Habitat Significance		*				400
RESTORATIVE CAPACITY (10 Percentile Annual Rainfall)						
Less than 50 mm					*	402 x 2
50 mm to 100 mm				*		402
100 mm to 150 mm			*			400 x 2
150 mm to 200 mm		*				400
200mm to 250 mm	*					Clear
GEOMORPHOLOGY						
Sites of Significance			*			402+400
Flinders Ranges		*				400
DRAINAGE PATTERN						
Stream Channels			*			402
Salt Lakes			*			402
ARCHAEOLOGICAL AND ETHNOGRAPHIC SITES						
Sites of Significance					*	406
High Archaeological and Ethnographic Site Density				*		404
High/Medium Site Density			*			402
Medium Site Density		*				400 x 2
Medium/Low Site Density	*					400
Low Archaeological and Ethnographic Site Density	*					Clear
LANDSCAPE VALUES						
Outstanding Grade				*		404+400
Very High Grade			*			402+400
High Grade		*				400
Other	*					Clear
ACCESS AVAILABILITY						
Nearest Access Road greater than 30 km			*			402+400
Nearest Access Road between 1 and 30 km		*				400
Within 1 km of Existing Access Road	*					Clear
SOIL TYPES						
High Erosion Potential					*	402+400
High to Moderate Erosion Potential				*		402
Moderate Erosion Potential			*			400 x 2
Low to Moderate Erosion Potential		*				400
Low Erosion Potential	*					Clear
SEISMIC RISK						
Fault Line			*			402
LAND UTILISATION						
Unallocated Crown Land			*			402+400
Town Areas			*			402
Pastoral Land		*				400
Agricultural Land	*					Clear
LAND USE PLANNING ZONES						
Class A Areas				*		404+402
Class B Areas			*			402
Class C Areas	*					Clear
AREAS OF CONSERVATION SIGNIFICANCE						
National Park/Conservation Park					*	406
Extension to National Park			*			402
Private Resort and Sanctuary			*			402
Forest Reserve			*			402

Figure 2. Composite overlay of environmental constraints [3]

Environmental constraints associated with specific sites, i.e., national parks, conservation parks, Aboriginal sites and rare species habitat, were given high ratings, not only to reflect high impact potential, but also to ensure their visibility on the final overlay. Constraints such as increased access and erodibility were given lower ratings because the impacts are more diffuse, and if darker toning were used, the contrast in tone would be lost in the composite overlay.

No great significance should be placed upon the relative weights used. The overlay was designed to create a visual impression and it is unlikely that the eye perceives the relative darkness of tone in direct proportion to the density of grey. The densities created by the grey shades are actually in geometric progression, whereas the visual impression is more arithmetic (or linear) progression. Also, in the photographic integration and final printing, the blackness of the darker toning is softened. Furthermore, the overlay process is not sensitive to relative weights. Considerable differences in relative density of grey would result in the same general visual impression. With the assignment of these weights, it is possible to combine all of the environmental constraints into a composite map (Figure 2). The brown lines shown on Figure 2 indicate the alternative pipeline alignments that were identified as possible routes and subjected to more detailed engineering, economic and environmental assessment [3].

2.3 Comparative analysis of alternative pipeline alignments

2.3.1 Alternative alignments

Seven alternative alignments, shown in Figure 3, were subject to comparative analysis in the environmental impact assessment process [3]. As can be seen from the topography in Figure 3, there is a mountain range, the Flinders Ranges, on the direct alignment between Moomba and Stony Point. Thus, alignments to the west and to the east of the ranges were considered. There were also operational advantages in following the existing natural gas pipeline route from Moomba to Adelaide, at least to Compression Station 4 (northeast of Martins Wells).

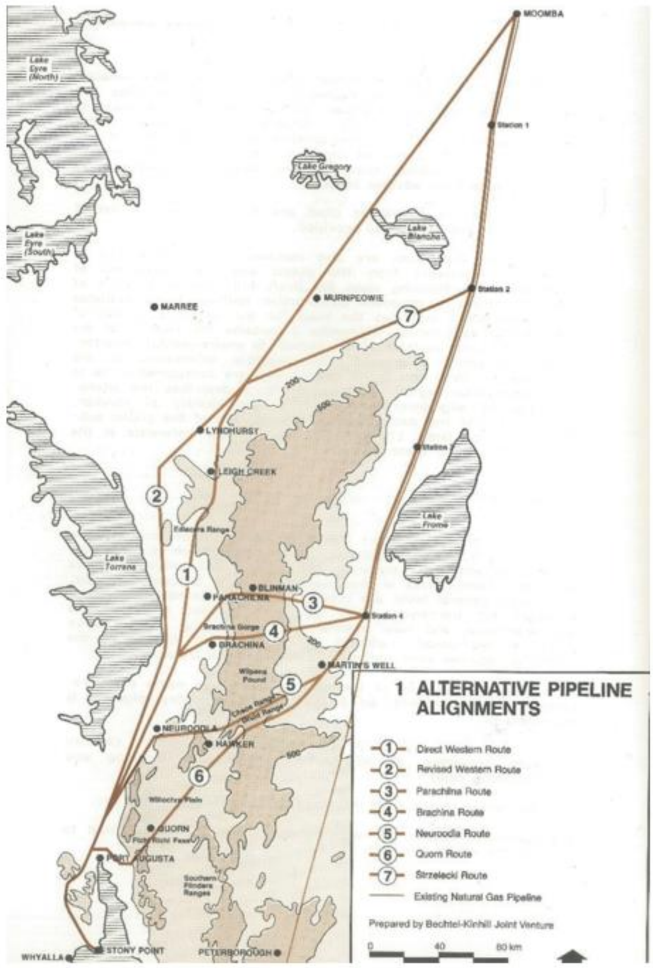

Figure 3. Alternative pipeline alignments [3]

The Direct Western Route (alternative 1 in Figure 3) is the shortest route (626 km) but traverses significant areas where rock is close to the surface. The rock can be avoided by a slightly longer route (632 km)-the Revised Western Route (alternative 2). For the alignments on the eastern side of the Flinders Ranges, there is a need to cross the ranges. Four alignments which minimise elevation were considered:

Parachilna Route (alternative 3), Brachina Route (alternative 4), Neuroodla Route (alternative 5) and Quorn Route (alternative 6) with the Neuroodla Route being the shortest of the eastern alternatives at 659 km. An intermediate option, the Strzelecki Route (alternative 7), following the Moomba to Adelaide natural gas pipeline to Compression Station 2 then crossing to the western side of the Flinders Ranges was raised in public comments on the draft environmental impact statement and was evaluated in the final environmental impact statement [3].

2.3.2 Comparative analysis

An overall summary of route dependent differences in relation to potential environmental effects as well as engineering and economic factors is given in Figure 4. The table in Figure 4 provides a subjective assessment of the relative importance of the different factors which are pertinent to the comparison of alternative alignments.

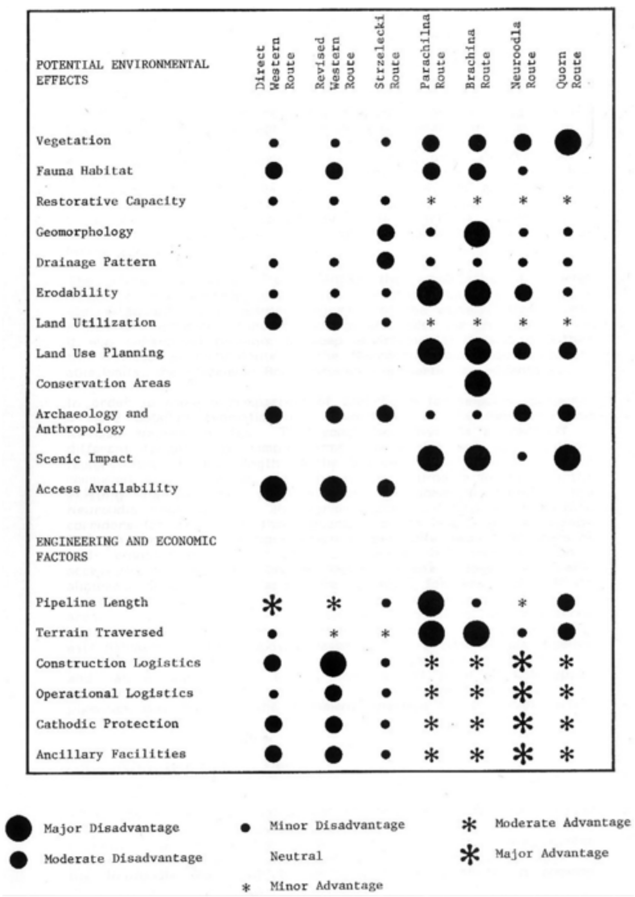

Figure 4. Overall summary of route dependent differences

For the western alignment options, environmental impacts are comparable, while the easier terrain traversed by the Revised Western Route was seen to outweigh the slightly shorter alignment of the Direct Western Route. Of the eastern routes, both the Parachilna and Brachina Routes traverse higher environmental values in the Flinders Ranges and offer no engineering or economic advantages. Of the other two routes, the Neuroodla Route generally avoids areas of high environmental value in the Flinders Ranges and has a number of engineering and economic advantages over the Quorn Route. Thus, of the eastern alternatives, the Neuroodla Route is the preferred alignment. The Strzelecki Route offers neither the advantages of shorter length of the western alignments, nor the construction or operational of the greater common alignment of the eastern alternatives.

2.3.3 Further evaluation of the revised Western and Neuroodla routes

Buried pipelines when adequately revegetated represent a temporary impact upon the land- scape. Associated facilities such as access roads, communication towers, pump stations, power supplies and mainline valves are permanent features that have long-term impacts. Thus, principal environmental concerns relate to: the prospect of revegetation of the pipeline right-of-way, the need for new infrastructure services and the impact of the new facilities required.

In relation to revegetation potential in the critical areas of comparison for the two routes, the higher, more reliable rainfall through the Flinders Ranges makes the prospect of revegetation in the area of concern for the Neuroodla Route greater than for the area of concern for the Revised Western Route. The low unreliable rainfall in the far north between Lyndhurst and Moomba reduces the likelihood of successful rehabilitation. With respect to new roads and powerlines, the Neuroodla Route can be adequately serviced by the existing road network. This is also the case for the Revised Western Route south of Leigh Creek. However, north of Leigh Creek, upgrading of roads and new powerlines would be required. There would also be impacts associated with a new pipeline access road which would cross sand dune country. For the Neuroodla Route, communication towers in the scenic areas of the Flinders Ranges would require careful siting to reduce visual impacts.

From the further analysis of environmental impacts, the Neuroodla Route was considered to have more manageable environmental effects compared to the Revised Western Route. The Neuroodla Route was the selected alignment for the Moomba to Stony Point pipeline.

3. AFTERMATH

3.1 Review of environmental performance

The hydrocarbon liquids pipeline was constructed in 1982 and twenty-five years after that, an environmental impact report was prepared [6] to meet the requirements of the South Australian Petroleum Act 2000 as per section 97 of the Petroleum Regulations. The report reviewed the actual and potential environmental impact of the pipeline operations and maintenance. It also summarised stakeholder consultation and issues raised by government agencies in relation to environmental effects of the pipeline.

The 659 km pipeline has an outer diameter of 355.6 mm and is buried at least 800 mm below the surface. There are four pump stations approximately 150 km apart but only the one at Moomba is still in use. Mainline valves have been placed approximately every 25-30 km so that a section of the pipeline can be shut down if there is a sudden drop in system pres- sure or to isolate a section for maintenance. Each mainline valve site has a scraper station to allow cleaning devices (pigs) to be inserted or removed from the pipeline. There are cathodic protection test posts about 1.5 km apart to monitor the effectiveness of the corrosion protection system.

The following activities have the potential to cause environmental impacts or affect land- owners or occupiers along the pipeline:

- maintenance of the pipeline and facilities such as excavations of pipeline segments for maintenance, hydrotesting, pipeline integrity testing and welding;
- maintenance of the pipeline easement including weed control, and rehabilitation of erosion and excavation sites;
- maintaining access to the pipeline easement;
- inspection of the pipeline easement and facilities;
- emissions from the pipeline; and
- potential accidents and emergency situations.

The environmental regions traversed by the pipeline comprise:

- channel country (Moomba to 27 km point) dominated by parallel sand dunes and interconnected clay pans;
- dunefields (27-162 kmp) with extensive undulating sand dunes and numerous small clay- pans;
- stony plains (162-215 kmp and 234-314 kmp) with gently sloping gibber plains with drainage lines in the north and wide floodplains and occasional dunes in the south;
- Flinders Ranges (215-234 kmp and 314-505kmp) characterised by high quartzite hog- back ridges with loamy soils and intervening plains and lowlands with duplex soils i.e., soils with contrasting textures between soil horizons, that are prone to gullying;
- Western pastoral (505-659 kmp Port Bonython) characterised by a sandy alluvial plain with numerous lakes and parallel dunes changing to granite hills with gentle footslopes, and a plateau with steep escarpments, long footslopes and undulating plains with low dunes.

In the time since construction, the pipeline easement has for the most part revegetated to a state similar to the adjoining land. Only the access track north of pump station 2 in the channel country and the dunefields and major facilities remain visible and relatively free of vegetation. There is also vegetation removal from the right-of-way within 2 m of the pipeline centreline to maintain line-of-sight.

Excavations for pipeline maintenance occur up to 30 times per year involving holes about 5 m × 4 m (in area) by 2 m (deep). They typically remain open for 2 weeks. Revegetation undertaken as part of the excavation reinstatement process has been dependent on seasonal conditions and rainfall. This means regrowth can take several years. Concerns that needed to be addressed in excavation restoration were to ensure topsoil was returned to the surface and avoid compaction of duplex soils.

There are 22 watercourses crossed by the pipeline. In the twenty-five years of operation there has been erosion or pipeline exposure at six locations. The erosion was most frequently observed in the right-of-way in the Flinders Ranges section of the pipeline, where climate and terrain result in ephemeral drainage lines.

The most significant contamination associated with the operation of the pipeline was land and groundwater contamination associated with burn pits at Pump Stations 2 and 3 and Neuroodla. Liquid hydrocarbons released during maintenance and pigging activities were dis- charged to burn pits and disposed of by burning. As a result, contamination of the burn pit and areas in the vicinity of the pit occurred. This practice no longer occurs, and any liquid hydrocarbon waste released during maintenance and pigging activities is discharged to containment systems and collected by a waste contractor. Monitoring and remediation of areas of potential contamination has been completed over a number of years, with soil removed to landfarms.

Risk of fire is a concern. There were no recorded fires along the pipeline route but in June 2001, an explosion and fire damaged the liquids pumping station at Moomba. Three employees were performing routine maintenance when an escaping mixture of hydrocarbons ignited. One man died from his burns, another received burns to his neck and hand while the other man escaped injury.

Of concern to pastoralists is unauthorised people gaining entry to properties via the pipe- line access road. There were instances of cutting locks and fences, and leaving gates open. Government authorities were concerned about third party use of the right-of-way leading to degradation of the northern part of the state.

During infrastructure upgrades, a number of cultural heritage surveys have been under- taken. Two areas of high sensitivity have been located in the dunefields region and one in stony plains region. Sites in the dunefields of the Western pastoral region and in the channel country have also been identified.

3.2 Refinements to impact analysis based on operation and maintenance experience

The analysis for the constraint mapping was primarily focussed on the impacts of the pipe- line construction. The operation and maintenance experience provides insights to refine the impact analysis for the pipeline post-construction. Each of the elements for defining pipeline constraints are considered below.

3.2.1 Vegetation associations

Vegetation recovery along the pipeline right-of-way indicates that pipeline construction was a temporary impact. However, the access road involves a permanent loss of vegetation. Use of the existing access road for the Moomba to Adelaide gas pipeline from Moomba to Pump Station 3 near Martins Wells (i.e., Compression Station 4 on the gas pipeline in Figure 3) has avoided the permanent impact of a new access track for 350 km of the pipeline route.

An operational consideration is the management of weeds and their potential spread through operation and maintenance activities. While the inspections indicate that the density and abundance of weeds is comparable to adjoining land, there has been a need to address declared weeds such as African Rue and Buffel Grass through weed control programmes especially on the northern parts of the pipeline route.

3.2.2 Significant fauna risk

The operational risks to fauna are associated more with the access road and excavations for maintenance activities rather than the pipeline right-of-way. The access road represents a permanent habitat loss and fauna mortality through roadkills. Excavations for pipeline maintenance can cause temporary loss of habitat and potential entrapment.

3.2.3 Restorative capacity

Both for pipeline right-of-way and operational disturbance, rainfall has been a key factor in rehabilitation success: this supports the constraint mapping indicator.

3.2.4 Geomorphology, drainage pattern and erosion

While significant landforms were avoided through route selection, one of the most frequently mentioned issues in annual reports and environmental reviews has been the erosion on creeklines during floods following high rainfall events. This is an issue both for environmental impact and pipeline integrity. Engineering treatments, such as gabions, reno-mattresses and box culverts have been required. The impacts have been most significant on the eastern margins of the Flinders Ranges, e.g., Mt Chambers Creek and Mulligan Spring Creek, where steeply sloping sections have erosion potential during floods and the red duplex soils are very susceptible to gullying.

3.2.5 Land utilisation, land use planning, areas of conservation significance and scenic areas

Areas of significant land use sensitivity were avoided through pipeline route selection. Following the construction of the pipeline, the land use above the pipeline (principally grazing and cropping) was able to resume with the exception of excavation activities immediately above the pipeline. There were localised impacts, such as short-term reduction in available pastoral grazing and cropping land during excavations, temporary cutting of fences to allow operational access, and use of access tracks on pastoral properties [7]. Concerns raised by landholders were that unauthorised people are gaining access via the pipeline easement, cut- ting locks and fences, and leaving gates open [6].

3.2.6 Archaeological and ethnographic sites

While specific sites have been avoided, during infrastructure upgrades a number of cultural heritage surveys have been undertaken locating sites of archaeological and ethnographic sig- nificance. The surveys have confirmed the high sensitivity in the Dunefields region and in the Stony Plains region. Sites in the dunefields of the Western Pastoral region and in the channel country have also been confirmed for their archaeological significance.

3.2.7 Access availability

The operational concerns about unauthorised access and the degrading effects of third-party use of the right-of-way confirm the significance of avoiding the creation of new access to areas currently protected by their remoteness.

3.2.8 Overall impact

Based on the environmental impact report of pipeline operations, an analysis of the environ- mental significance of the past events and potential impacts associated with the proposed activ- ities was undertaken against assessment criteria for classifying environmental impact. The pipeline operation and maintenance have been classified by the regulator as ‘low impact’ [7]. The avoidance of impacts by pipeline route selection using constraint mapping and ongo- ing operational management of environmental impacts appear to be keeping impacts to a manageable level.

4. CONCLUDING COMMENTS

With multiple environmental factors and alignment options, constraint mapping was valuable in systematically documenting the potential significance of environmental impacts associated with pipeline alignments between Moomba and Stony Point. Constraint mapping provided the basis for the identification of possible routes, the comparative analysis of alternative alignments and areas requiring more detailed evaluation.

The aftermath analysis provided general support for the basis for constraint mapping. It indicated that revegetation over the buried pipeline had been achieved and that erosion at creek crossings was an ongoing issue for environmental impact and pipeline integrity. Other operation and maintenance issues requiring attention were excavations for pipeline maintenance, hydrocarbon releases during maintenance activities and unauthorised access on pipe- line access roads. Also highlighted was the sensitivity of cultural heritage sites.

With constraint mapping for avoiding sensitive areas during route selection and the ongoing management of operations and maintenance activities, the pipeline has been classified as low impact by the regulator.

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