A CASE STUDY OF SOIL CONSERVATION MONITORING FOR LARGE LINEAR ENGINEERING IN CHINA: THE WEST TO EAST NATURAL GAS PIPELINE

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Abstract
The “West to East” natural gas pipeline is one of the largest linear engineering programs in China. This paper introduces and discusses the soil conservation monitoring for the project (west segment). Monitoring consisted of investigation and sampling of soil loss, landscape disturbance, and the erosion control effect of soil conservation measures by periodical terrestrial monitoring and remote sensing. Data from monitoring plots and survey showed that construction of the 2330 km pipe engineering crossing northwest China significantly induced soil erosion in several ecologically fragile areas, and parts of the soil conservation engineering needed to be improved for the security of gas pipe engineering. Analysis of the periodical monitoring indicated that the critical threat of soil erosion will be serious after the main construction has finished. Maintenance of soil conservation measures should be the primary erosion control work in the next decade.

Additional Keywords: soil erosion; monitoring; infrastructure engineering; western China

Introduction
The “West Development Project” brings historic impacts on the natural environment in western China mainly by infrastructure construction in the past 4 years, which evokes rising attention on soil erosion and relevant new ecological issues. Linear engineering, such as highway and pipe engineering, is one of the most important types of infrastructure engineering. However, there is still a lack of relative research. In order to provide a case study of soil conservation for large linear engineering in China, this paper introduced and preliminarily discussed the soil conservation monitoring for the “West to East” Natural Gas Pipe Engineering (west segment).

China started to build the “West to East” Natural Gas Pipe engineering for its sharply rising energy consumption several years ago. This project (Lunnan to Shanghai, more than 3900 km) which cost 43.5 billions RMB (about 5.2 billion USD) is the largest gas pipe engineering program in China, and will provide natural gas for 85 million families in eastern China. In December 2003, the construction of the 2330 km west segment was finished. The west segment starts from Lunnan, Xijiang autonomous region, and ends in Jingbian, Shaanxi province. It will transport natural gas from Xijiang to Jingbian pressurization station. Being different from the east segment crossing dense population regions in east and central China, the west segment crosses the low population regions in northwest China where soil erosion and land degradation is very serious.

Wind erosion is the main erosion type in west segment of the pipe engineering. In several hilly sections, hydraulic erosion makes impacts while most parts of the west segment are plain and arid/semi-arid areas. Annual precipitation is less than 100 mm at the starting points in the west (Lunnan pressurization station), and almost 88% of the whole west segment is located in areas where annual precipitation is less than 200 mm. In the last 280 km at the east section, annual precipitation increases to 400 mm. Except several natural oases and farming areas, most parts of the west segment are short of vegetative cover, and typical landscapes are degraded or desertificated temperate arid/semi-arid grasslands and deserts. The west segment of the pipe engineering can be divided into 4 sub-segments based on geographical difference (from west to east, Figure 1): (1) west sandy desert region (from Lunnan, Xingjiang to Hami, Xinjiang; about 620 km), (2) gravel desert region (from Hami, Xingjiang to Jiuquan, Gansu; about 720 km), (3) desertificated grassland peneplain and sandy desert region (from Jiuquan, Gansu to Zhongwei, Ningxia; about 630 km), (4) desertificated grassland region (from Zhongwei, Ningxia to Jingbian, Shaanxi; about 360 km). Man-made disturbance on land surface in these ecological fragile areas will easily cause unrecoverable impacts, such as vegetation destruction and accelerated soil erosion. Spring (especially March to April) is the season in which wind velocity attains the top in the year for most parts of the west segment, and is the season of most serious wind erosion. In summer (especially July to September), hydraulic erosion possibly appears in hilly sections after limited rainstorm. The soil erosion control measures for the pipe engineering were designed, and most of the discharged soil and debris during the construction has been treated well, also (Wang Hong, Zhang Zhizhong, Wang Ruifang *et al*., 2003). However, soil disturbance and vegetation destruction still can cause serious soil erosion during the construction (especially during the pipe flume digging). After the construction finished, it was still difficult for artificial surface covers to prevent soil erosion occurring in the next springs when wind erosion is more likely. In hilly sections (although their length is very short comparing with the whole west segment), it is still possible that heavy rainstorms can cause a temporary flood threat and hydraulic erosion even when the vegetation begins to recover.

In order to monitor and assess the impacts of soil erosion and land degradation caused by the pipe construction, the monitoring centre of soil and water conservation, Ministry of water resources of China started a monitoring project in March 2003 when main construction began. The monitoring project is still in progress. In this paper, only the data obtained before January 2004 was discussed. Regarding to the requirement of the "Technical code of practice on water and soil conservation monitoring SL277-2002" (Ministry of water resources of the P.R.China, 2002), that monitoring is consisted of three parts: (1) monitoring on soil loss, (2) monitoring on landscape disturbance, and (3) the monitoring on erosion control effect of soil conservation measures.

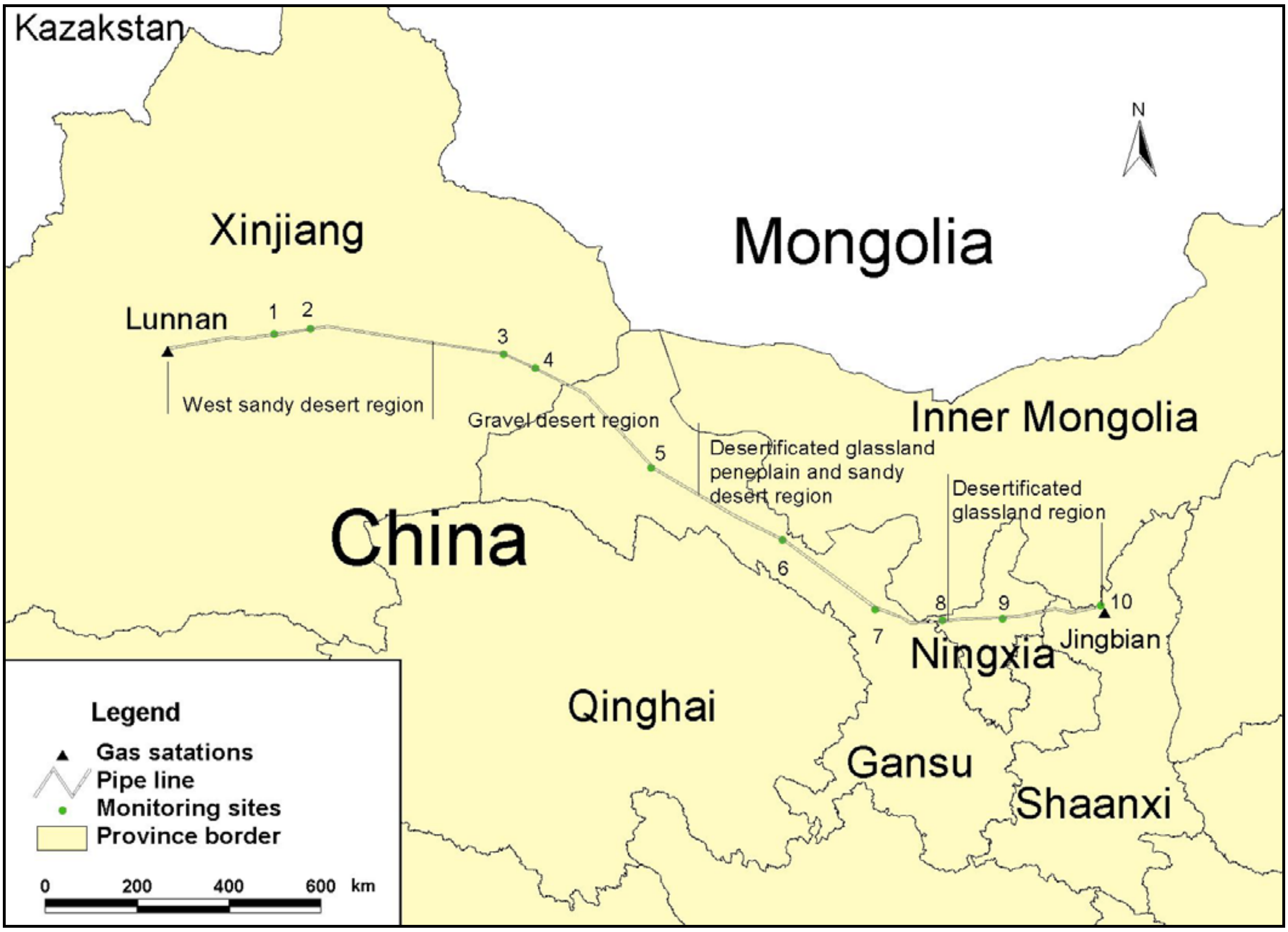

Figure 1. Map of the soil erosion monitoring sites and pipe line

Materials and Methods

Methodology

Soil erosion caused by construction of large linear engineering is a dependant on meteorological, geomorphologic and vegetative factors. Therefore, sufficient ground monitoring sites are the first critical basis of the methodology. Unfortunately, it's very difficulty to set up and maintain numbers of observation sites in these desertificated areas or deserts. Basing on the division of the geographical parts, the monitoring project established 10 constant sites along the whole pipe (see Figure 1). Besides ground monitoring, the monitoring project takes route survey and remote sensing as the other two bases of the methodology. Both the methods of route survey and remote sensing were based on the Chinese technical code SL277-2002.

The surveyors measured soil erosion along the pipe in the seasons when serious erosion may occur. The main task of the route included surveying erosion intensity and area, measuring vegetative cover ratio and sampling soil density for typical section, and investigating the effect of soil erosion control measures. There were route surveys in April, August, and December in 2003. After the surveys, SPOT 5 and IKONOS images of 10 typical sections were analysed. Remote sensing was to provide supplement and comparison data for each constant site. Eight SPOT 5 images and two IKONOS images were applied, and nine images covered constant sites (not including site No. 8). Most of these images were received when the pipe engineering was under construction during March to November in 2003 (except the IKONOS image covers site No. 9). Basing on the images and surveys, the buffer areas of pipe which crossing monitoring sites will be assessed. Assessment of different soil erosion intensity grades was based on the interpretation by the Chinese technical standard SL190-96 (Ministry of water resources of the P.R.China, 1997). The interpretation of soil erosion gradation from images was based on artificial recognition. The minimum analysed length of buffer areas (500 m distance from the pipe at each side) was 20 km for SPOT, and 5 km for IKONOS.

Monitoring sites

The monitoring sites include 10 constant sites (key sites) and 24 temporary sites. Constant sites (Table 1 and Figure 1) were established for key sections where soil erosion may be serious owing to the construction and geographical conditions. Temporary sites were set for temporary task, such as observation of hydraulic erosion in a hilly section, or monitoring the short-term serious disturbance on the surface when the pipe construction crossed river, or traffic line. All the constant sites are located in the areas where wind erosion is the dominant type of soil erosion.

Table 1. Monitoring site locations

Site No.	Location	Landscape	Sub-segment
1	Southern Bohu, Bohu county, Xinjiang	Sandy hemi-desert plain	West sandy desert region
2	Kumishi, Tuokexun county, Xinjiang	Valley, desert	
3	Nanhu, Hami city, Xinjiang	Gravel desert peneplain and sandy dune	Gravel desert region
4	Eastern Hami, Hami city, Xinjiang	Gravel desert plain	
5	Diwopu, Yumen city, Gansu	Gravel desert plain	
6	Laosimiao, Zhangye city, Gansu	Edge of the ravel and sandy desert plain	Desertificated peneplain and sandy desert region
7	Notheast Gulang, Gulang county, Gansu	Belt of transition between the sandy desert and desertificated grassland	
8	Yinshui, Zhongwei county, Ningxia	Desertificated grassland Peneplain and sandy desert	
9	Hongsipu ecomonic district, Ningxia	Desertificated grassland plain	Desertificated grassland region
10	North Jingbian, Shaanxi	Desertificated grassland plain	

For wind erosion monitoring, each constant site includes three observation plots: plot of original landscape (near by the pipe construction), plot of recovering zone (inside the pipe construction zone after the construction finished and vegetation began to recover, same geomorphologic location as the original plot), and plot of disturbance zone (inside the pipe construction zone when constructing). The first two plots are constant, and are observed in the first day and 15th day of each month. If the wind erosion is very strong, the interval can be adjusted and be shortened to 10 days. Temporary sites have two plots: one original, and one plot of disturbance zone. These two plots (area of rectangle can be adjusted to the constructing area) are maintained until the backfill and are observed twice: at the beginning and the end of the observation period. The plot of disturbance zone was just maintained before the dug pipe flume was backfilled. Each plot (both of constant sites and temporary sites) for wind erosion observations are a 20 m×50 m rectangle, and its long edge is perpendicular to the main wind direction. Plots have no real material border, but just signal strings in order to decrease the impact on wind blowing. Stagger lined graduated sticks (wooden or concrete, 50 cm high and diameter of 1 cm, scale on mm) for erosion measurement were vertically nailed into the earth in plots on the density of 1 stick/4 m×4 m. The graduation of surface height of each stick was recorded each time, and soil erosion quantity during two observations can be estimated by the average height of all the sticks.

In three temporary sites of hilly areas, plots are designed for hydraulic erosion. Each site also includes two plots as above (1 original, and 1 disturbed zone). Each plot (0.5-1.0 ha) is an entire natural slope with physical border (long edge along the slope direction), and soil loss quantity was estimated by the measured sediment deposition in the small gully (steel board was set at the outlet to intercept lost sediment from the slope) at the bottom of the slope. These sites are observed twice at least: beginning and the end of the observation period. If there has been a rainstorm, an observation should be started as soon as possible.

Observation

Items and measuring method of the observations in plots are in terms of the Chinese technical code SL277-2002. The items mainly include: (1) major meteorological data (e.g. precipitation, wind velocity and lasting time), (2) soil eroded depth, (3) vegetative structure and cover ratio, (4) soil structure, texture, bulk density and soil moisture percentage. Observations on monitoring sites started from August, 2003.

Results

For the reason of data reporting delay, only part of the data is available for analysis till January 2004. The route surveys and remote sensing images showed the construction zone was strictly less than 30 m in all sections, and all the sections have applied with erosion control engineering (small sediment interception dam, flood prevention wall, and locomotive sand prevention barrier, etc) where necessary to do so according to the design. More than 25 soil erosion control structures were investigated during the surveys, and three of them were destroyed by flood while five of them were seriously damaged by runoff flow. None of the wind erosion control engineering was seriously damaged or out of function. Because the image interpretation is still in process, the complete data of soil erosion area in each typical section covering the constant monitoring site are still unavailable.

The major data available are those observed from constant monitoring sites. There are some typical data of soil erosion from several constant monitoring sites in Table 2. Ten temporary sites are also available. Three of these 10 sites, the three temporary sites of hilly areas for monitoring hydraulic erosion showed no measured soil loss from slope from August to December for no heavy rains. Table 3 shows the typical soil erosion data during the pipe engineering constructing. The other available data include the vegetative cover ratio and vegetative structure of each typical section by vegetation investigation during the route surveys.

Table 2. Data available from typical constant monitoring sites

Site No.	Period	Percentage of available graduated sticks		Average eroded/deposited soil depth (mm)		Estimated soil erosion/deposition quantity (t km^{-2})	
		Original surface	Disturbed zone	Original surface	Disturbed zone	Original surface	Disturbed zone
5	November 15-December 1	98%	89%	1.44	0.67	1,656.0	2541.5
8	November 15-December 1	!00%	100%	0.30	0.30	354.0	354.0
9	September 15-November 30	!00%	100%	0.12	0.13	168.0	182.0
10	December 1-December 10	100%	89%	-0.78	0.25	-951.6	305.0

Note: negative value means deposition.

Table 3. Soil erosion quantity of typical constructing period
(Temporary monitoring site No.19, Hongsipu economic district, Ningxia)

Plot	Monitoring period	Number of available graduated sticks	Average eroded/deposited soil depth (mm)	Estimated soil erosion/deposition quantity (t km^{-2})
Original (degraded grassland)	August 30 – September 10, 2003	15	1.67 (Deposited)	2,054.1
Disturbed zone	August 30 – September 10, 2003	15	0.80 (Eroded)	3,038.1

Discussion

Although acquired data were not sufficient for assessing the soil erosion for the pipe engineering, some data indicated the impact of construction in several typical sections. Basing on the analysis by route survey and preliminary remote sensing, the construction did not enlarge the disturbed zone along the pipe, even in desert regions. No significant difference caused by the construction was found on the SPOT and IKONOS images between the 500 m buffer of the construction zone and the outside area. All of the farmland and forest (both in very limited area) has been artificially recovered with vegetation on which crop and wild vegetation has been cleaned up by the pipe construction. But the vegetation recovery of grassland disturbed was lagged for lack of artificial grass planting, especially in the sub-segment of desertificated grassland peneplain in Gansu province. For instance, the average NDVI in constructing zone of remote sensing image covering constant site No. 7 was less than 1/3 of that index of original landscape. That will possibly induce serious wind erosion in the spring. Although erosion control measures were applied in hydraulic erosion threatened areas, serious soil erosion still occurred in several sections in the summer. Three flood prevention walls were destroyed by flood after rain, although the average gradient of these sites is around 9%. Five were seriously damaged in Xinjiang during July and August 2003. That not only caused serious erosion around the pipe zone, but also destroyed most vegetation and flushed almost all the topsoil there. Even more, the earth ridge over the backfill of gas pipe was flushed. The annual precipitation in these areas is less than 100 mm there, but the limited rainfall was concentrated in middle and late summer. The survey indicated the threat of runoff in those arid areas was low-estimated by the designers of erosion control engineering and the erosion monitoring projects (none hydraulic erosion monitoring sites set there while no soil loss by hydraulic erosion measured in the monitoring sites).

Some of the graduated sticks for monitoring were blowed down by strong wind, but the percentage of unavailable sticks did not exceed 20% in each plots. Because of being short of comparison plots, the soil erosion quantity was estimated by arithmetic mean of the eroded depth but not by statistic calculation. The arithmetic mean still indicated obvious difference (constant site No. 5 & 10, Table 2) where lack of sufficient surface cover after the construction. According to that estimation, soil erosion by wind increased by 53.5% in constant site No. 5 where no artificial cover material or grass planting was applied. The same reason caused very serious wind erosion in 10 days in constant site No. 10: compared with original landscape, the erosion intensity attained to 1256.6 t km^{-2}. These two sites are located in the key eco-fragile regions in China: the Hexi oasis corridor and the Shaanxi-Shanxi-Inner Mongolia desertificated zone. It is very difficult for natural rehabilitation after topsoil loss and original vegetation destroyed in these areas. Generally, natural vegetation cover ratio is not able to attain its original level in 10 -20 years after complete cleaning as for construction.

In spite of the good treatment of excavated soil and rock debris from the construction zone, the piled soil from pipe flume digging has not been treated as well. Table 3 shows a typical example. Without effective temporary covers, the bondless piled soil and bare pipe flume will be highly erodible bed. Temporary site No.19 is an example of this near villages and farms, serious wind erosion (estimated soil erosion exceeded 5,000 t/km^2) during the construction undoubtedly was a threat.

Conclusions

Large linear engineering disturbs the landscape as a narrow zone during its construction. In arid/semi-arid regions, the zone will exist for a long time if there is a shortage of necessary artificial erosion control measures, such as grass planting and stalk/rock debris covering. The analysis and discussion in this paper is very preliminary, because the major data will presumedly be obtained in the spring of 2004 when is the main season of wind erosion (average wind velocity from November to December is less than that from March to April at least by 20% in most monitoring sites), and the serious soil erosion in some sections after construction finished may last for years. However, the data obtained so far still showed some impact on soil erosion by the "West to east " natural gas pipe engineering in 2003.

Preliminary analysis by route survey and remote sensing showed the disturbed areas were strictly limited within the impact buffer (width 1 km), and the width of directly effected zone under construction was less than 30 m. Nevertheless, plots observation in several monitoring sites showed that construction obviously induced soil erosion in ecological frangible areas for being lack of sufficient surface cover during/after the construction, and parts of the soil conservation engineering needs to be improved or rebuilt for the security of gas pipe and the protection of the soil and vegetation in hydraulic erosion effecting sections. As the result of serious erosion possibility for the difficulty of the natural vegetation recovering, maintenance of soil conservation measures should be the first work for erosion control in the next decade.

More data by observation are critical for further analysis and study. However, route survey and remote sensing still showed the advantages to the shortage of monitoring site. Route survey and patrol survey is essential for the investigation and measurement of the effect of soil erosion control engineering, and for those serious erosion after paroxysmal flood and strong wind blow. Remote sensing is very helpful for identifying the range and extent of disturbance along a complete typical section where is under the impact by construction. After the interpretation of images and analysis of soil samples is finished, the impact of landscape borders and shapes changing during the construction and early period of vegetation recovery can be analysed. This will be very useful for studying soil erosion expanding from a narrower buffer.

It is unknown whether the construction of the pipe discussed in this paper will evoke serious soil degradation and strengthen the wind erosion on the disturbed surface (on where the perennial wind direction is close to the pipe line) years later when the climate gets warm and dry? The question has been raised since sand storms became serious in northwest China in recent years. Study on it needs to set more monitoring sites and plots on soil properties and meteorological parameters in the long term.

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