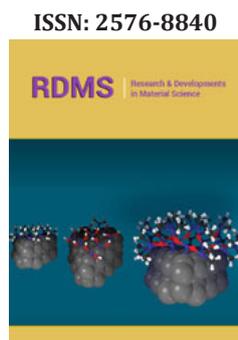


River Flood Monitoring for Prediction of Hazards for Pipeline System

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Abstract

Today advances in information systems, satellites imaging systems and improved software technologies have led to opportunities for a new level of information products from remote sensed data. The integration of these new products into existing response systems can provide a wide range of analysis tools and information products on the base of developed geographical information system (GIS). Using the higher resolution of space imagery and change detection analysis natural disaster awareness and damage assessment can be conducted rapidly and accurately. On the base of the developed database the use of the remote sensing methods and GIS technology provides resources and opportunities of prediction and reduction of natural risk due to the timely implementation of appropriate engineering and technological activities.

This paper describes results of study of island and channel forming processes on the Kura River and its crossing with linear system oil or gas pipeline. The aim of this study is to analyse the current condition of the pipeline and assess the potential threats to its integrity, identify the remediation measures for the Kura River crossing and ensure that the proposed methods allow to retain the integrity of the pipeline.

Keyword: Remote sensing and geographical information system; Linear system; Data processing; field measurement; Satellite image

Introduction

The Kura river is the largest river of Azerbaijan. It stretches for 1,515 kilometers and covers an area of 188 thousand sq. km. The Kura River originates from the Hel River in Turkey, passes through Georgia and Azerbaijan and flows into the Caspian Sea in South-Eastern part of the country.

There are number of oil and gas export pipelines in Absheron peninsula, Azerbaijan, which cross the Kura River downstream of the important road and railway bridges. The investigated area of pipeline crossing the river stream is located at the North-West of Azerbaijan. Prior to the pipeline construction at the investigated area an island was formed and continued growing in the center of the river, downstream of the bridges and near the river crossing. The formation and growth of the island has a significant impact on the channel morphology. It resulted with certain effects to the linear system integrity.

The bridge piers maintain the river channel stability preventing lateral movement in this area. However, downstream the river movement and the bridge openings allow the river some freedom of direction. In this paper the results of the studies performed for the Kura River crossing were analyzed and the recommendations provided for appropriate authorities for further decision-making stage.

Methodology

This study was carried out to identify the most critical impacts on the linear pipeline integrity caused by the Kura River. With this purpose the following data was studied and analyzed:

- A. Information regarding flow rates, water consumption and turbidity;
- B. Satellite images indicating island growth and the river channels transformation over time;

C. Information regarding yearly change of the Kura River and island based on geodetic and topographical data;

D. Information regarding yearly change of the river channels width and depth based on the river sections; and

E. Field survey results provided by Company.

Based on the collected information from different sources, the annual changes of the river were studied, the most critical and sensitive points identified and the minimum measures that would provide a reliable solution to support the linear system integrity developed.

Study and analysis

Statistical data has been collected, reviewed, and topographical maps and sections compared to identify the yearly change in the Kura River sleeves and island between 2007 and 2016. The use and application of space technology is suitable in many cases, particularly for the case of river flow rate estimation due to the covering a large area, high accuracy, availability of application in the unacceptable areas etc. Moreover, according to the created and developed database there is an advantage to be very sensitive to any available change occurred in the investigated areas.

The benefits of analysis of natural risk reduction involves a number of particular challenges, including:

A. Little related information may be available on the frequency and intensity of the hazard event implying uncertainty about the level of risk.

B. Many of the benefits of any natural risk reduction measures, whether undertaken in the context of a disaster risk reduction project or as part of another type of development project, are related to the direct and indirect losses that will not ensue should the related hazard event occur constantly, rather than streams of positive benefits that will take place, as would be the case for other investments. This can present certain measurement difficulties.

Problem description

Subsequent to pipeline construction, an island of presumably alluvial origin had further formed in the center of the river, downstream of the bridges and near the river crossing. This island is seen on satellite image from 2001 (Figure 1, 2), however, the construction works of the railway bridge in 2013 could have an influence on the island growth as the river bed was not cleaned properly upon completion of the activities which was necessary to keep the river downstream in working condition. The alluvial island in the Kura River channel represents a plot of land of elliptic shape stretched in an east-west direction with an area of 101597.687 in 2016 (measurements are taken within boundaries of section #4-#4a). The island is formed with coarse sand and gravel material. The landscape of the island is hilly, the maximum difference between the lowest (202.10) and highest (205.59) elevations is 3.5m (according to topographical survey of 2013). The island is partly covered with vegetation.



Figure 1: River plan at Kura West crossing 2001.

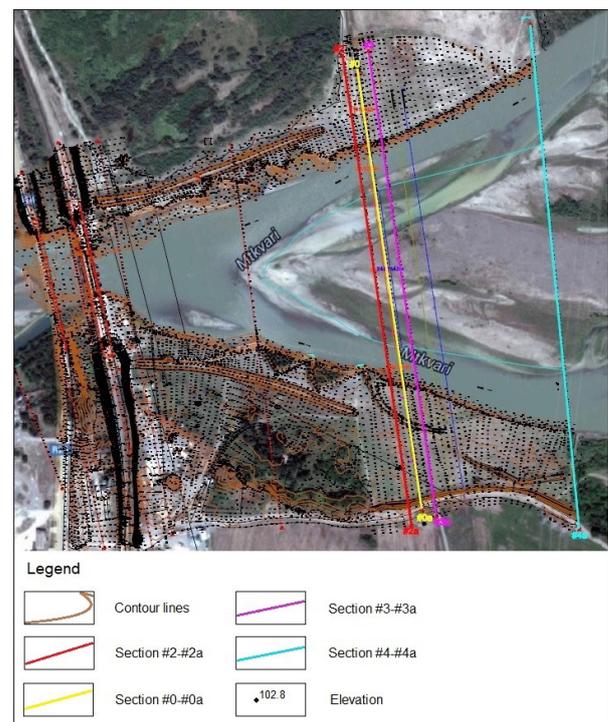


Figure 2: River plan at Kura West crossing 2016 (merged with topographical map of 2016).

There are two ways that the island could have formed in the Kura River channel:

A. A secondary channel could diverge from the main channel, encircling a portion of the floodplain before returning to the main river;

B. A blockage within the active channel could have resulted in sediment deposition and the emergence of the island.

The mechanism of the gravel bar formation is based on the interaction of zones of washout and sediments deposition at high flow levels. During base flow conditions, river basins are sites of flow-pathway divergence and therefore sediment deposition. Riffles are sites of flow convergence and therefore erosion. When flow levels approach bank full, the relationship reverses, and sediments are washed out from river basins and deposited on the

crest of downstream riffles. As the river level falls, the top of such riffles may appear as a gravel bar.

A second method of gravel bar formation commences when a piece of large woody debris lodges in the river channel. The tree roots can serve as a barrier to flow, thus the flowing water must diverge around the obstruction. At the point where the stream diverges around the roots, the stream velocity decreases and sediment deposition can occur. The alluvial island formed in

the Kura River channel has grown larger during the past years. According to topographical maps provided by Company, the area of the island changed as is presented in Table 1 (area was calculated within boundary of section #4-#4a). As can be seen from Table 1, the area of the island significantly increased between 2008 and 2016 from 17521.518m² to 101597.687m². Although there was a single island, between 2010 and 2013 this land was divided by two and four small plots of land. However, in 2014 these plots formed a uniform island again.

Table 1: Yearly change of alluvial island area.

| Year | Island Area, m ² | Note |
|------|-----------------------------|---|
| 2007 | 38090.406 | |
| 2008 | 17521.518 | |
| 2009 | 87379.199 | |
| 2010 | 90263.498 | Total island area consists of two plots of land with areas of 17378.990m ² and 72884.508m ² |
| 2011 | 92830.115 | Total island area consists of four plots of land with areas of 2641.358; 5560.793m ² ; 7459.47m ² ; 77168.491m ² |
| 2012 | 106496.485 | Total island area consists of four plots of land with areas of 2796.504m ² ; 1527.368m ² ; 9745.504m ² ; 92427.109m ² |
| 2013 | 128515.714 | Total island area consists of two plots of land with areas of 3920.468m ² ; 124595.273m ² |
| 2014 | 134796.334 | |
| 2015 | 135469.375 | |
| 2016 | 101597.687 | |

River history

According to the information provided by the Ministry of Ecology and Natural Resources, the Kura-Giragkesemen hydrological station located in Giragkesemen village of Agstafa district has been used since 06.07.1985. The catchment basin of the Kura River is 35900km², flood periods are spring and autumn, shallow waters are observed in winter and summer. During the observation period the average water consumption during flood period was equal to 301m³/s, during shallow water this dropped to 137m³/s. Maximum water consumption in the river was registered on 28.04.2005 (2496m³/s), minimum on 21.08.2000 (36m³/s). Maximum water level was registered on 12.06.1987 (669cm), minimum on 24.08.2010 (196cm).

During the observation period the average registered water velocity was equal to 1.21m/s, and maximum velocity was 3.80m/s. Maximum turbidity in the river water is 5500g/m³. Within the boundaries of the investigated area, the Kura River represents the main river channel divided by two sleeves (left and right) due to the presence of an alluvial island in the middle of the river. Information regarding yearly change in river behavior along the section #0-0 is presented in Table 2 where width and depth of the river as well as distance of the river bank from the pipeline, was compared between 2009 and 2016. Table 3-5 represent the same information for sections #2-#2a, #3-#3a and #4-#4a. Information sources provide various values for the water consumption of the Kura River. In our calculations we used the average water consumption of 301m³/s, provided by the Ministry of Ecology and Natural Resources.

Table 2: Kura River yearly data 2009-2016 along section #0-#0a.

| Year | Island Width, m | Left Sleeve | | | | Right Sleeve | | | |
|------|-----------------|-------------------------|---------------------------------|--|-------------------------------------|--------------------------|----------------------------------|---|--------------------------------------|
| | | Width of left sleeve, m | Maximal depth of left sleeve, m | Cross section of left sleeve, m ² | River flow rate in left sleeve, m/s | Width of right sleeve, m | Maximal depth of right sleeve, m | Cross section of right sleeve, m ² | River flow rate in right sleeve, m/s |
| 2009 | 169.7 | 87.33 | 2.35 | 84.64 | 2.94 | 113.71 | 0.93 | 67.42 | 2.88 |
| 2010 | 149.3 | 91.00 | 1.00 | 85.46 | 2.61 | 96.00 | 1.00 | 70.24 | 3.13 |
| 2011 | 122.2 | 98.00 | 1.00 | 84.63 | 2.17 | 100.00 | 2.00 | 94.75 | 2.74 |
| 2012 | 166.9 | 97.31 | 2.50 | 107.3 | 2.64 | 54.51 | 2.05 | 65.69 | 2.44 |
| 2013 | 261.1 | 57.04 | 2.32 | 95.68 | 2.82 | 50.18 | 1.90 | 57.40 | 3.01 |
| 2014 | 257.4 | 62.89 | 2.03 | 69.74 | 3.66 | 48.25 | 1.71 | 54.78 | 3.25 |
| 2015 | 257.5 | 65.14 | 2.19 | 98.23 | 2.88 | 46.02 | 1.95 | 56.80 | 2.82 |
| 2016 | 243.15 | 68.93 | 2.71 | 137.3 | 2.01 | 69.05 | 3.06 | 123.99 | 1.35 |

Table 3: Kura River yearly data 2009-2016 along section #2-#2a.

| Year | Island width, m | Left Sleeve | | | | Right Sleeve | | | |
|------|-----------------|-------------------------|---------------------------------|--|-------------------------------------|--------------------------|----------------------------------|---|--------------------------------------|
| | | Width of left sleeve, m | Maximal depth of left sleeve, m | Cross section of left sleeve, m ² | River flow rate in left sleeve, m/s | Width of right sleeve, m | Maximal depth of right sleeve, m | Cross section of right sleeve, m ² | River flow rate in right sleeve, m/s |
| 2009 | 158.51 | 112.69 | 1.93 | 83.19 | 2.99 | 92.93 | 0.91 | 66.21 | 2.93 |
| 2010 | 131.4 | 87.73 | 1.43 | 82.5 | 2.71 | 98.31 | 1.35 | 82.54 | 2.66 |
| 2011 | 101.79 | 127.31 | 1.53 | 99.87 | 1.84 | 105.05 | 3.42 | 199.2 | 1.3 |
| 2012 | 152.01 | 108.07 | 2.37 | 140.35 | 2.02 | 46.72 | 2.45 | 73.3 | 2.18 |
| 2013 | 249.13 | 63.3 | 1.98 | 83.29 | 3.24 | 39.74 | 2.69 | 63.19 | 2.74 |
| 2014 | 248.42 | 67.68 | 1.4 | 75.06 | 3.4 | 38.43 | 2.77 | 62.76 | 2.99 |
| 2015 | 247.62 | 70.66 | 2 | 104.07 | 2.71 | 41.31 | 2.9 | 79.76 | 2.01 |
| 2016 | 228.86 | 77.42 | 3.51 | 201.44 | 1.33 | 59.77 | 3.56 | 108.03 | 1.54 |

Table 4: Kura River yearly data 2009-2016 along section #3-#3a.

| Year | Island Width, m | Left Sleeve | | | | Right Sleeve | | | |
|------|-----------------|-------------------------|---------------------------------|--|-------------------------------------|--------------------------|----------------------------------|---|--------------------------------------|
| | | Width of left sleeve, m | Maximal depth of left sleeve, m | Cross section of left sleeve, m ² | River flow rate in left sleeve, m/s | Width of right sleeve, m | Maximal depth of right sleeve, m | Cross section of right sleeve, m ² | River flow rate in right sleeve, m/s |
| 2009 | 188.34 | 79.61 | 2.52 | 67.29 | 3.70 | 107.25 | 0.87 | 67.68 | 2.87 |
| 2010 | 166.54 | 89.69 | 1.91 | 88.35 | 2.53 | 95.19 | 1.41 | 81.0 | 2.71 |
| 2011 | 143.02 | 89.78 | 1.61 | 78.15 | 2.35 | 92.68 | | 82.08 | 3.16 |
| 2012 | 174.13 | 89.94 | 2.42 | 105.07 | 2.69 | 61.22 | 1.77 | 1.85 | 2.65 |
| 2013 | 273.48 | 51.36 | 2.38 | 99.39 | 2.72 | 49.62 | 1.69 | 51.51 | 3.36 |
| 2014 | 268.32 | 57.27 | 2.62 | 101.03 | 2.53 | 49.66 | 1.42 | 49.4 | 3.80 |
| 2015 | 267.72 | 60.97 | 2.64 | 101.3 | 2.79 | 47.22 | 1.76 | 59.73 | 2.71 |
| 2016 | 251.21 | 71.85 | 3.74 | 187.63 | 1.42 | 62.28 | 2.45 | 107.45 | 1.55 |

Table 5: Kura River yearly data 2009-2016 along section #4-#4a.

| Year | Island Width, m | Left Sleeve | | | | Right Sleeve | | | |
|------|-----------------|-------------------------|---------------------------------|--|-------------------------------------|--------------------------|----------------------------------|---|--------------------------------------|
| | | Width of left sleeve, m | Maximal depth of left sleeve, m | Cross section of left sleeve, m ² | River flow rate in left sleeve, m/s | Width of right sleeve, m | Maximal depth of right sleeve, m | Cross section of right sleeve, m ² | River flow rate in right sleeve, m/s |
| 2009 | 312.90 | 64.83 | 1.20 | 41.44 | 3.28 | 54.95 | 2.11 | 75.78 | 4.69 |
| 2010 | 329.98 | 66.94 | 1.69 | 69.6 | 3.21 | 99.36 | 1.49 | 86.73 | 2.53 |
| 2011 | 408.31 | 103.45 | 1.33 | 77.89 | 2.36 | 81.24 | 2.26 | 105.47 | 2.46 |
| 2012 | 403.93 | 118.29 | 1.30 | 123.49 | 2.29 | 79.83 | 1.88 | 96.98 | 2.29 |
| 2013 | 416.91 | 70.6 | 2.05 | 97.16 | 2.78 | 81.12 | 1.30 | 68.41 | 2.53 |
| 2014 | 409.43 | 80.55 | 1.64 | 81.64 | 3.13 | 78.97 | 1.25 | 70.75 | 2.65 |
| 2015 | 395.68 | 93.09 | 1.28 | 99.50 | 2.84 | 81.77 | 0.59 | 33.05 | 4.85 |
| 2016 | 347.30 | 128.97 | 2.86 | 243.14 | 1.10 | 96.98 | 1.72 | 125.37 | 1.33 |

Island formation:

A. The width of the island along section #0-#0a increased by 73.45m (from 169.7m in 2009 to 243.15m in 2016).

Changes observed in the left sleeve of the Kura River are as follows:

B. The width of the sleeve decreased by 18.4m (from 87.33m in 2009 to 68.93m in 2016).

C. Maximum depth of the river increased by 0.36m (from 2.35m in 2009 to 2.71m in 2016).

Changes observed in the right sleeve of the Kura River are as follows:

D. The width of the sleeve decreased by 44.66m (from 113.71m in 2009 to 69.05m in 2016).

E. Maximum depth of the river increased by 2.13m (from 0.93m in 2009 to 3.06m to 2016).

Island formation:

A. The width of the island along section #2-#2a increased by 70.35m (from 158.51m in 2009 to 228.86m in 2016).

Changes observed in the left sleeve of the Kura River are as follows:

B. The width of the sleeve decreased by 35.27m (from 112.69m in 2009 to 77.42m in 2016).

C. Maximum depth of the river increased by 1.58m (from 1.93m in 2009 to 3.51m to 2016).

Changes observed in the right sleeve of the Kura River are as follows:

D. The width of the sleeve decreased by 33.16m (from 92.93m in 2009 to 59.77m in 2016).

E. Maximum depth of the river increased by 2.65m (from 0.91m in 2009 to 3.56m to 2016).

Island formation:

A. The width of the island along section #3-#3a increased by 62.87m (from 188.34m in 2009 to 251.21m in 2016).

Changes observed in the left sleeve of the Kura River are as follows:

B. The width of the sleeve decreased by 7.76m (from 79.61m in 2009 to 71.85m in 2016).

C. Maximum depth of the river increased by 1.22m (from 2.52m in 2009 to 3.74m to 2016).

Changes observed in the right sleeve of the Kura River are as follows:

D. The width of the sleeve decreased by 44.97m (from 107.25m in 2009 to 62.28m in 2016).

E. Maximum depth of the river increased by 1.58m (from 0.87m in 2009 to 2.45m to 2016).

Island formation:

A. The width of the island along section #4-#4a increased by 34.40m (from 312.90m in 2009 to 347.30m in 2016).

Changes observed in the left sleeve of the Kura River are as follows:

B. The width of the sleeve increased by 64.14m (from 64.83m in 2009 to 128.97m in 2016).

C. Maximum depth of the river increased by 1.66m (from 1.20m in 2009 to 2.86m to 2016).

Changes observed in the right sleeve of the Kura River are as follows:

D. The width of the sleeve increased by 42.03m (from 54.95m in 2009 to 96.98m in 2016).

E. Maximum depth of the river decreased by 0.39m (from 2.11m in 2009 to 1.72m to 2016).

Summarising the analysis of the river history, we can conclude that the river sleeves along the considered sections #0-#0a, #2-#2a and #3-#3a decreased in width with time except for section #4-#4a.

River banks erosion

River banks erosion process reflects the interaction of the river stream and its channel. Together with erosion, the accumulation of alluvial material is observed on the opposite bank (in our case, on the island coast). The intensity of erosion depends on the angle of the stream towards the river bank: the greater the angle, the higher the erosion rate. In the straight river channel, the stream center is in the center of the channel and therefore the river velocity is at its maximum in the center of the channel and minimum at the river banks (in this case the section of the river is close to a parabola form) and no erosion is observed. When the river stream is angled towards the river bank, the convergence of streams occur near the bank and stream velocity increases due to its constriction.

Thus, river bank erosion occurs which often forms a steep cliff. The water table skewness stipulates the beginning of circulating stream with ground flow directed from the eroded bank. As the ground flows contain maximum amount of alluvia, the direction of the stream leads to formation of riverine shelves, which in turn leads to higher constriction of the river channel. As a result, the parabolic form of the river channel tends to a triangle formation.

Discussion

Based on the river and island histories and studies, we can outline general tendencies in the Kura River behavior, island growth and river banks erosion. The river banks at the section #0-#0a are reinforced with rip raps and therefore the potential of erosion at these points is not high. The river sleeves at the pipeline crossing tend to decrease in width and increase in depth, which looks to be the biggest threat to the pipeline in its current state. The cross section of each sleeve also increases (at points where the pipelines cross the river). However, the flow rate (the ratio between inertial forces and viscous forces) is higher in 2016, which is due to decreased values of wetted perimeters of the river sleeves.

Further growth of the alluvial island and subsequent narrowing of the river sleeves can possibly bring to a change in sleeve depths. However, the fact that there is no information regarding the material of the river bed, makes it difficult to predict its behavior. The material of the alluvial island is mainly gravel and coarse sand with some topsoil potentially brought by the river stream. The water in the Kura River is muddy and the stream velocity is high enough to bring necessary sand and gravel material from upstream.

Therefore, we may expect that the island forming processes will continue in the future with further constriction of the Kura River sleeves in the pipeline section. Hence, the issue must be addressed, and preventive measures undertaken prior to the further growth that has the potential to damage the pipeline.

To protect the pipeline, which is located under the Kura River bed, it is necessary to minimize the river depths in the sleeves where the pipeline crosses as is shown on Figure 3 & 4. For that the river bed must be backfilled with clay and covered with protecting gravel and pebbles layers. This alone however will bring to unpredictable

results due to further increase of flow rates in the sleeves. To avoid this, i.e., to decrease flow rates and increase stability, it is necessary to increase the sleeves' width by excavation of soil at the alluvial island shores. Excavation covers the areas where the river sleeve width is critically low and increased water flow may cause erosion of the beds. Another preventing issue is the coastal line reinforcement after increasing the widths of the sleeves, i.e. the banks of the island must also be reinforced using rip-rap. It also is important to provide a uniform section of the river in the areas where the pipeline is located, as shown in Figure 5. This will minimize the disturbance of the riverbed by unstable flows and locally increased turbulences.

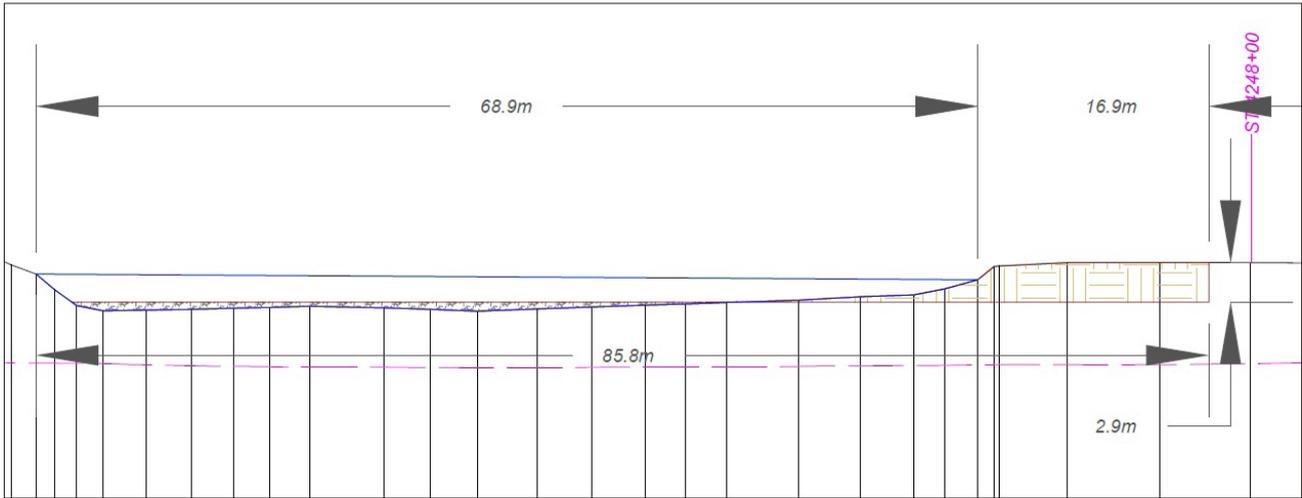


Figure 3: Section of the left sleeve with proposed actions (yellow shaded area indicates the excavation of the island shore; grey shaded area shows installation of the backfill material on the river bed).

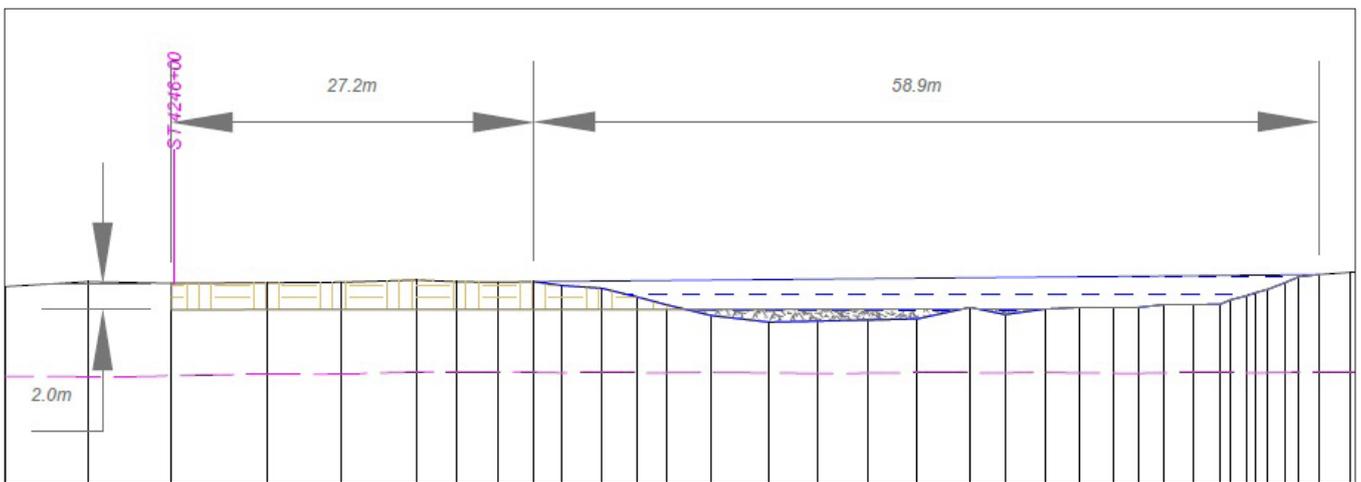


Figure 4: Section of the right sleeve with proposed actions (yellow shaded area indicates the excavation of the island shore; grey shaded area shows installation of the backfill material on the river bed).

Recommendation

The principal problem at present appears to be the right sleeve of the river. Hence, it is recommended to consider widening of this sleeve area and reinforcing its river bed. This can be implemented by:

A. Conducting a river bed investigation to obtain information regarding river bed material.

B. Excavating the river bank on the side of the island to enable sleeve widening (Figure 5): 5728m³ from the left shore of the island and 5894m³ from the right shore of the island. More detailed analysis and exact profiles will be developed during the following stages, where water flows will be considered and means to avoid turbulence developed.

C. Fill the river bottom in the area of the sleeve with clay and put a rip rap on its surface to minimize water depths and prevent

further washing out (amount of backfill material is 12730m³ for the left sleeve and 10436m³ for the right sleeve).

D. When conducting these works, attention shall be paid to arranging a profile such that the water stream influence on erosion is minimal (construe an optimal angle).

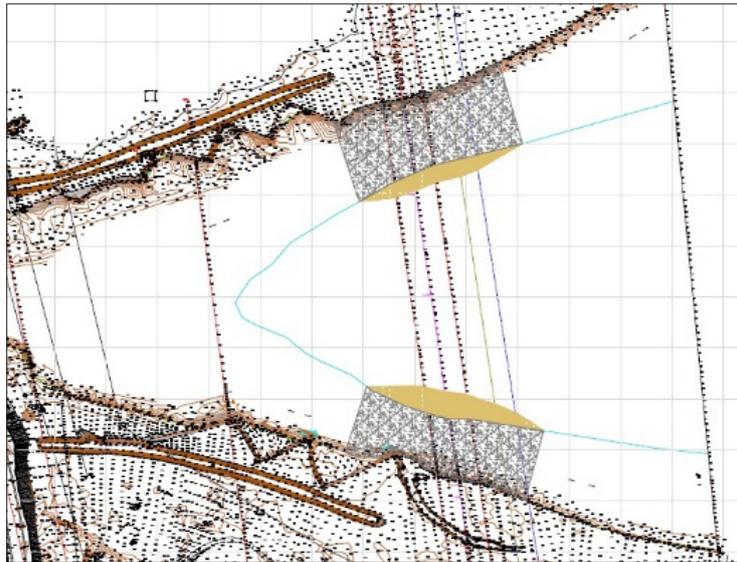


Figure 5: Proposed actions for Kura River crossing remediation (yellow shaded area indicates the excavation of the island shores; grey shaded area shows installation of the backfill material on the river bed)..

Conclusion

Based on above measurements it can be concluded below items as outcomes of the research work:

A. The river banks at the areas of the pipeline crossing remain intact due to reinforcement. This however resulted in the river bed deepening (due to alluvium).

B. The water depth on the right sleeve of the river has significantly increased and may constitute a risk to the pipeline integrity.

C. The narrowing of the sleeves is another threat to the pipeline as it may further tend to deepen the water levels. As the banks are reinforced (riprap), and the island size increases due to alluvium, the river bed is being washed out.

D. The material of the river bed at the point of maximum water depth is unknown (e.g. it's potential for being washed out and its permeability).

E. The cross section of the river sleeve in the pipeline crossing areas increases with the flow velocity decreasing, however this results in river bed deepening, which may threaten pipeline integrity.

A more precise data related to the subject river area were requested from the Ministry of Ecology, including water velocities and maximum overflows. Those will be required to develop a detailed design and calculations.

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