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Diversion of Nala Passing Through the Coal Blocks-Hydrologic and Hydraulic Prerequisites

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Abstract: **Coal reserves in India are one of the largest in the world. Exploiting this vast potential is necessary for the economic growth of the country. Many times it becomes necessary to divert natural streams for mining the coal available beneath them. Keeping the hydrologic regime of the upstream and downstream of the mining area is a prerequisite for the environmental protection in addition to many other environmental issues. This paper describes the hydrologic and hydraulic prerequisites of diversion of Nalas with a case study of Jitpur coal block in Godda district of Jharkhand. KewariNala is flowing through this mine area, which needs to be diverted. Alignment of the Nala diversion was proposed to be along the western boundary of the coal block. Simulations of the flow in KewariNala were carried out under existing as well as after diversion of Nala using one-dimensional mathematical model, HEC RAS under steady state flow conditions. Based on the analysis of Meteorological data, hydrological data, topographical data and result of model studies it was found that the design parameters of proposed diversion plan of KewariNala in Jitpur coal block is feasible. The diversion channel has been designed so that the water regime under existing and diverted condition for the common reach of KewariNala is undisturbed. Thus, design for diversion of KewariNala along the western boundary of the coal block has been suggested with due care on hydraulic aspects.**

Keywords: **Extreme Value Analysis, Flood Routing, Simulation, Mathematical Modeling**

1. Introduction

In India's energy sector, coal accounts for over 50% of primary commercial energy supply. With the economy poised to grow at the rate of 8-10% per annum, energy requirements will also rise at a level of 6% (approx.). Coal will continue to be a dominantcommercial fuel two decades from now and beyond, despite our nuclear energy programme, development of natural gas supplies, increased hydropower generation, and emphasis on renewables [1].Coal reserves in India are one of the largest in the world. As on April 1, 2012, India had 293.5 billion metric tons (323.5 billion short tons) of the resource [2]. In order to extract the natural coal resources, diversion of small streams or Nala sometimes becomes inevitable considering economical growth. There is a proposal of establishing a Thermal Power Plant (TPP) of capacity 2 x 660 MW in Godda district of Jharkhand. The required coal will be catered from Jitpur Coal Block-300 Ha, located 10 km from TPP in Godda district. It is proposed to perform open cast mining operations to extract coal. There is a Nala, KewariNala, a tributary of Gumani River, flowing in north-south direction through this mine area, which practically divides the area in two halves. Two sub-Nalas (Nala 1&2) joins main KewariNala from Western side and two small Nalas are contributing from Eastern side. The total length of KewariNala from its origin near Chotaudaliupto its confluence with Gumani River is 12.70 km. Its total catchment area uptoGumani River is 67.33 km^2. The elevation at the origin is as high as 357m. The upper most reach is steep, where as the downstream reach is having mild slope. The elevation at the outfall near Gumani River is about 100m. The main KewariNala catchment upto the plant entry point has been estimated as 35 Km^2. Large amount of coal is underlying below the bed of Nala at a depth of more than 60–70 meters. So there is need of diversion of this Nala, to free the coal block for mining activities (Figure 1).

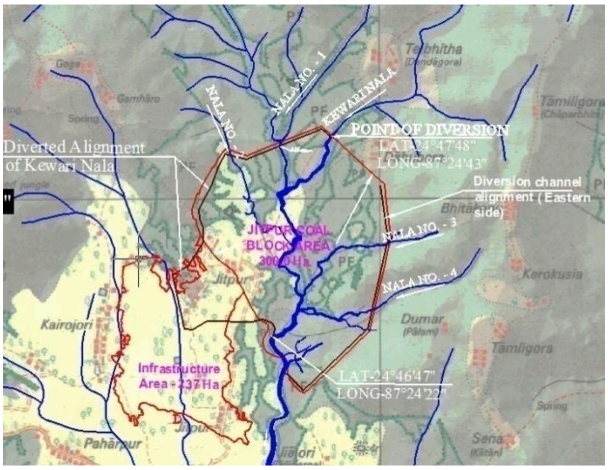

Fig.1. Coal Block Map Indicating KewariNala&Nalas1,2, 3 and 4

2. Literature Review

According to the Ministry of Coal, India is currently the third largest producer of coal in the world, with a production of about 407 million tons (MT) of hard coal and 30 MT of lignite in 2005–06. India has significant coal resources, but there is considerable uncertainty about the coal reserve estimates for the country. Without improvements in coal technology and economics, the existing power plants and the new plants added in the next 10–15 years could consume most of India's extractable coal over the course of the plants' estimated 40-year to 50-year life spans. Indian coal demand, driven primarily by the coal power sector, already has been outstripping supply; over the past few years, many power plants have restricted generation or have partially shut down because of coal supply shortages. Hence, heavy investments in the coal sector, particularly in underground mining, will be needed to increase the pace of domestic coal production. Coal imports are also projected to increase significantly over the next 20 to 25 years, with important implications for the Indian coal industry, as well as for the national and financial security of the country. The demand for coal in India's power plants has rapidly increased since the 1970s, with power plants in 2005–06 absorbing about 80% of the coal produced in the country. Other key coal consumers are the steel and cement industries. The demand for coal in India is expected to increase rapidly in the future, dominated mainly by the power sector. There is worldwide concern about increased coal use, as greater carbon dioxide (CO_2) emissions from coal combustion will exacerbate climate change. At the same time, there are now a number of different existing and emerging technological options for coal conversion and greenhouse gas (GHG) reduction worldwide that could potentially be useful for the Indian coal-power sector [3].

Natural streams are comprised of a heterogeneous mosaic of habitats, created by gradients of hydraulic variation and complex sedimentation patterns [4]. Diversions also have the potential to change in-stream sedimentation processes, but quantifying this is complicated by high natural temporal and spatial variability of flow and sediment regimes [5]. Stream flow diversions often produce extended drought like periods, with lower flow volume and velocity. These conditions coupled with higher water temperatures and less flow connectivity, lead to the reduction of benthic habitat area and quality [6]. Other problems due to stream diversion are sediment deposition, increased sediment loading to downstream channel, lateral channel instability, erosion/channel incision/ head cuts/ streambed scour/ bed degradation, stream channel dewatered, elevated water temperature, lack of riparian vegetation, accumulation of shrubs, trees, and debris along ditch, aquatic animal passage upstream and downstream, debris or sediment accumulation at diversion, inadequate water control, ditch failures, fish entrainment in ditch, operation and maintenance [7]. In spite of the problems associated with the Nala diversion, the coal mining operations for economical growth of India are of equal concern. Thus a solution to this problem is diversion of Nala in such a manner that even in a flood situation; the diversion does not affect the adjoining areas in any respect, such that the hydraulic conditions at the upstream and downstream of diverted Nala stay same as, those before diversion.

Rainfall analysis is used for Nala's flood estimation. The analysis can be done by any suitable probability distribution methods. The annual maximum daily rainfall data has been fitted to five different probability distribution functions i.e. Normal, Log-normal, Pearson Type-III, Log Pearson Type-III and Gumbel Type-I extreme. The probable rainfall value for different return periods has been estimated. The analysis indicated that, the Gumbel distribution gives the closet fit to the observed data [8]. Also CWC's Flood Estimation Report has given Isopluvial maps indicating contours of same daily maximum rainfall for the different regions for different return periods. These Isopluvial maps were also used for determining extreme daily rainfall [9]. Unit Hydrograph (UH) is the most popular and widely used method for predicting flood hydrograph resulting from a known storm in a basin area. The flood calculated using hydrograph matched the flood frequency analysis based on observed peak discharge data for analysis done by Jain, 2003.

Solaimani simulated steady flow along 4 km end of Zaremrood River (upstream of the Tajan River) and flood hazard extends derived using HEC-RAS/HEC-GeoRAS.For simulating, HEC-GeoRAS was used to define the river channel and extract cross sections from the TIN, then the results of pre-RAS were imported to HEC-RAS with the steady flow data and the other required data for process and ultimately provided 2-5-10-25-50-100-year inundation extends. The results indicated that the hydraulic simulation performed by integrating HEC-RAS model with GIS is effective for floodplain managements in different scenarios of river training practices [11].

Hicks examined the viability of the HEC-RAS unsteady flow routine for flood forecasting through an application to the Peace River in Alberta and showed that the accuracy comparable to more sophisticated hydraulic models can be achieved. The results of this case study indicated that flood routing and flood level forecasting can easily be performed using the already familiar, public domain, HEC-RAS model. He also stated that employing this approach has the potential to save flood forecaster's time, both in terms of the minimal calibration effort required for the flood routing component and in terms of eliminating the need to run a second model to determine corresponding flood level forecasts [12].

3. Methodology

For assessing change in hydraulic parameters in KewariNala under existing as well as diverted conditions, an appropriate mathematical model capable of handling steady/unsteady flows was adopted. Floods from the upstream catchments influence the flow in the Nala reach. It is customary to adopt diversion flood which is just adequate to be handled by the designed diverted channel. Generally the largest observed non monsoon flood or non monsoon flood of 100 year return period is adopted as a diversion flood, or the capacity of the diversion flood should be worked out on the basis of the standard "Design Flood for River Diversion Works- Guidelines"[10]. The peak flood discharges of 25, 50 and 100 year return periods were estimated using Synthetic Unit Hydrograph (SUH) method (for Main KewariNala) and rational method (for small Nalas 1,2,3,4) taking into consideration of catchment area, catchment characteristics and estimated rainfall intensities for respective years. The rainfall intensities used for calculation were found by Gumbel Distribution and Isopluvial maps. Once the flood was estimated, the topography of KewariNala was simulated using cross section data. The model runs were taken for predicted flood levels under existing conditions and for diverted Nala for the three return period floods. The design of the cross sections of diverted Nala were based on Manning's formula, for a velocity not exceeding 5m/s for unlined channel; for lined channel it could go upto10m/s [10]. The cross section of the diversion channel is governed by several considerations such as topography, volume of flood to be handled and water levels during passage of monsoon and non-monsoon in consonance [10].

4. Rainfall Analysis

Hydrologic systems sometimes experience an impact of extreme events, such as severe storms, floods, droughts, landslides, earthquakes and tsunamis. The magnitude of an extreme event is inversely related to its frequency of occurrence. Therefore, the objective of this exercise is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions. Statistical analysis of hourly or daily rainfall data is carried out using Extreme Value Distribution– Type I (Gumbel). The cumulative distribution function of GEV I distribution is:

$$F(x) = \exp\{-\exp[-(x-\alpha)/\beta]\}, \text{ where } -\infty < x < +\infty \qquad (1)$$

Where, α and β are the location and scale parameters of the distribution. The parameters of GEV Type I distribution are determined by the Maximum Likelihood Method (MLM) as Monte Carlo studies show that the Maximum Likelihood Method (MLM) is appropriate in giving efficient parameter estimates of αandβ. The parameter estimation by MLM uses an iterative procedure to estimate α^* and β^*; which are:

$$\beta^* = \sum_i (X_i / n) - \left[\sum_i X_i \exp(-X_i / \beta^*) / \sum_i \exp(X_i / \beta^*) \right] \qquad (2)$$

$$\alpha^* = -\beta^* \log_e \left[\sum_i \exp(-X_i / \beta^*) / n \right] \qquad (3)$$

The following equation is commonly used to compute the required rainfall depth for different return periods using the parameters, $\alpha$and β, of the GEV- I distribution.

$$X_T = \alpha + Y_T \beta \qquad (4)$$

Where X_T is the estimated rainfall depth corresponding to T-year return period and Y_T is the reduced variate, which is computed from the following equation:

$$Y_T = -\ln\left[-\ln\left(1 - \left(\frac{1}{T} \right) \right) \right] \qquad (5)$$

The concept of return period is basic to extreme value analysis (EVA). Return period 'T' is defined as the average elapsed time between occurrence of an event E with a certain magnitude or greater. In other words event E would be equaled or exceeded in a period of T years. Return period can be related to probability p of exceedance of such an event[13]. The relationship between the return period and the probability of exceedance is given as T = (1/p).

Rain guage data from nine rain gauge stations namely Godda, Sunderpahari, Pathergama, Paraiyahat, Kairo, Hiranpur, Amjora, Amarpara and Borio were available for analysis. 30km from the site was taken as radius of influence. The stations falling inside the radius of influence were chosen for analysis. Amarpara station was discarded due to larger radial distance from project site (more than 30km). Also Borio and Kairo were discarded due to discontinuous data and ambiguous data respectively. Gumbel distribution was used for finding extreme daily rainfall for each of the considered stations for the three return periods- 25, 50, 100 year. These values of all the stations for individual return period were then averaged and Daily Extreme Rainfall (mm) for each return period was found as shown in Table I.

Table 1. Adopted Daily Extreme Rainfall for JitpurCoal Block Area Estimated Using EVA

Sr. No.	Return Periods	Daily Extreme Rainfall (mm)
1	25 - year	233.56
2	50 - year	266.40
3	100 - year	298.99

Isopluvial maps developed by IMD and published by CWC, for whole India, showing 25 year, 50 year, 100 year return period, 24-hour maximum rainfall were also used for comparison of the extreme rainfall estimation of the study area with the regional estimation. They were comparable and within acceptable tolerance limit. An Isopluvial map for 100 year return period 24-hour maximum rainfall is shown in Figure 2. The Daily Extreme Rainfall (mm) for each return period was found as shown in Table II.

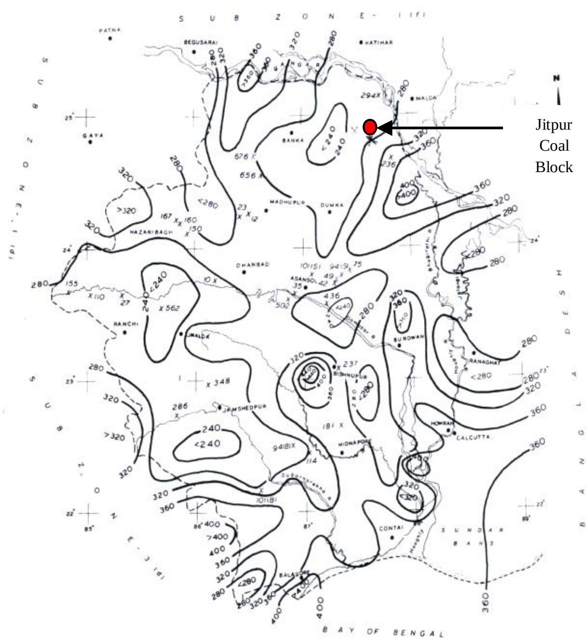

Fig.2. IsopluvialMap of 100 Year Return Period 24 Hours Rainfall (Mm) (FER Subzone-1g, 1994)

Table 2.Daily Extreme Rainfall for Jitpur Coal Block Area Estimated Using Isopluvial Maps

Sr. No.	Return Periods	Daily Extreme Rainfall (mm)
1	25 - year	220
2	50 - year	260
3	100 - year	280

5. Peak Flood Estimation

Unit Hydrograph was developed for KewariNala (Main Nala) using the physiographic characteristics of the catchment area- catchment Area, A(sq km), Length of the longest stream, L(km), Length of the longest stream from a point opposite to C.G. of catchment to point of study, L_c (km) and Equivalent stream slope, S (m/km). The developed Unit Hydrograph is as shown in Figure 3. Design storm duration was estimated as 3-hours. The 3-hour storm extracted from 24 hour rainfall of the respective return period was distributed into hourly distribution using CWC guidelines for determination of flood using Unit Hydrograph. The base flow recommended by CWC for this region was added as per SUH method [9] and peak discharges were calculated for the rainfalls estimated using EVA and Isopluvialmaps.These are given in Table III.

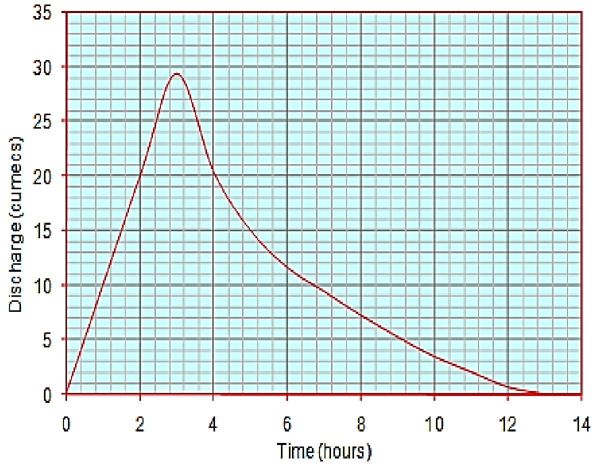

Fig.3. Synthetic Unit Hydrograph for Catchment Up To Coal Block Area

Table 3.Peak Discharges Using SUH Method for KewariNala(Main Nala) Upto Coal Block

Return Period	Peak Discharge in (m^3/s)	
	EVA	Isopluvial
25-Year	331.28	312.00
50-Year	377.61	368.55
100-Year	423.59	396.82

For the catchment area of Nala 1 and 2 (Sub Nalas to KewariNala from western boundary), the rational formula was used to estimate peak discharge, being it is a small catchment and time of concentration is of the order of 1-hour. The intensity of rainfall was estimated from the daily rainfall data (Estimated using EVA as well as from Isopluvial maps) using the CWC guidelines for this region for different return period rainfalls. Knowing the intensity of rainfall, catchment area and with an appropriate value of runoff coefficient, the peak discharge is computed using rational formula [13]

$$Q = 0.278\ CIA \qquad (8)$$

Where, Q= Peak discharge (m^3/sec)
C= Runoff coefficient (between 0 and 1)
I= Intensity of rainfall (mm/hr)
A= Catchment area (sq.km)

The runoff coefficients have been assigned on the basis of type of catchment area, land use and land cover details. In this case, the river Kewari originates from a hilly terrainand passing through the area, which is mostly forest. The peak discharges have been computed for Nala 1 and 2 having catchment area 13 km^2 as shown in Table IV.

Table 4.Peak Discharges Using Rational Method for Nala1 And 2

Return Period	Peak Discharge in (m^3/s)	
	EVA	Isopluvial
25-Year	169.8	160.0
50-Year	193.7	189.1
100-Year	217.4	203.6

6. Flood Routing Model

The choice of model for any prediction or simulation mostly depends on desired accuracy, extent and quality of data available for representing the prototype topography and boundary conditions. For this study, there was necessity of flow simulation with floods in KewariNala system. The HEC-RAS Beta 4 Version for the computation of water level was used for this study. Keeping present requirements in view, only hydrodynamic study for water flow simulation was adopted. Assuming, the Newtonian motion, the hydraulic parameters could be evaluated by considering the energy balance approach [13] at the two cross sections of a reach. Water surface profiles are computed at each cross section by solving the energy balance equation with an iterative procedure viz. standard step method.

The energy balance equation used for computing the water surface profile for a section of stream is given as below:

$$WS_2 + (\alpha_2 v_2^2 / 2g) = WS_1 + (\alpha_1 v_1^2 / 2g) + h_e \qquad (9)$$

Where,WS_1,WS_2= water surface elevations at cross sections 1& 2
v_1, v_2=average velocities (total discharge/total flow area) at section 1 & 2
α_1, α_2= velocity weighing coefficient at sections 1 & 2
g= gravitational acceleration
h_e= energy head loss

The energy head loss between two cross sections comprises friction loss and contraction or expansion loss.

The equation for energy head loss h_e is

$$h_e = LS_f + C\left|\{(\alpha_2 v_2^2 / 2g) - (\alpha_1 v_1^2 / 2g)\}\right| \qquad (10)$$

Where
L= discharge weighted reach length
S_f= representative friction slope between two sections and
C= expansion or contraction loss coefficient

Based on the above principles, Hydrologic Engineering Center (HEC), US Army Corps of Engineers (USACE), Davis, USA has developed one-dimensional model HEC-RAS [14]. The model is designed to perform one-dimensional hydraulic computations for a network of natural, as well as, constructed channels. The model can handle; a network of channels, a dendritic system, or a single river reaches. The steady flow component is capable of modeling sub critical, supercritical and mixed flow regime water surface profiles. The computational procedure is based on the solution of the one-dimensional energy equation. The energy losses are evaluated by friction (Manning's Equation) and contraction/expansion. It can also model flood plain inundations. In the present studies the steady flow in sub critical flow regime was considered as we are dealing the extreme flood conditions and model was used to perform hydraulic routing in steady state condition.

7. Simulation

Computations of water surface profile at all location of interest require channel geometry and flow data. Boundary conditions for flow modeling in natural streams are specified in terms of measured stage and discharges at upstream and downstream locations. Cross sections are required at representative locations throughout the stream and at locations where changes occur in discharge, shape, slope aspect and roughness, at locations where levels/flood embankment begins or ends and at bridge location. The basic geometric data consists of establishing the connectivity of the drainage system (river system schematic); longitudinal and cross section data; reach lengths; energy loss coefficients (friction losses, contraction and expansion losses); Stream junction information and hydraulic structure data (bridge, weir, culverts etc). The measured distances between cross sections referred to as reach lengths along the thalweg as well as the reach lengths for left over bank and right over bank are also required for modeling. In steady state flow modeling, the friction loss is modeled by Manning's equations. The selection of appropriate value of Manning's 'n' is significant to achieve accuracy of the computed water surface profiles. The discharge data are the most important data input for the computation.

A. Simulation under existing condition (Scenario I)

The total KewariNala reach of 5.8 km was simulated under scenario I out of which 2.8 km was within the coal block area and 3 km reach was extended downstream uptoGumaniriver for the mathematical model study. This extension was mainly done for comparison of various hydraulics aspects under pre and post scenario. The topography of river was reproduced in the model using cross-sections survey data of existing Nala. About 58 nos. of surveyed cross sections were given at representative locations throughout the stream in the coal block area. Figure 4 shows schematization of this reach. The model grid points indicate the location of river cross sections used for the study. The measured distances between cross sections referred to as reach lengths along the thalweg are shown in figure 4 as required for modeling. All these cross sections were appropriately extended on either side of the bank up to High Flood Level (HFL). The value of Manning's 'n' was appropriately selected as 0.025 under this scenario.

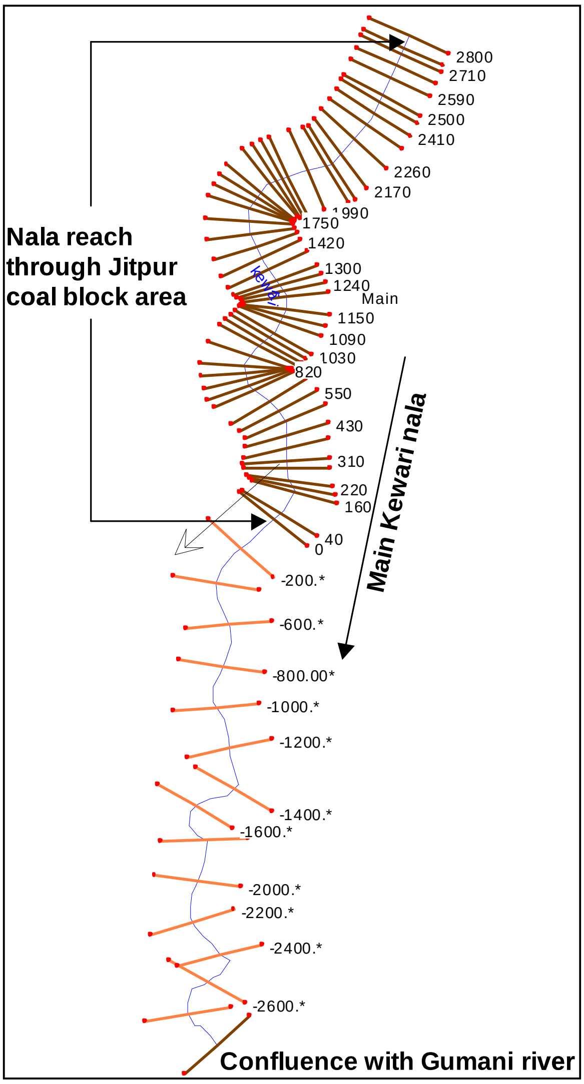

Fig.4. Schematic diagram of existing KewariNala reach under study (Scenario I)

B. Simulation under diverted condition (Scenario II)

The diversion Nala reach of about 4.05 km along the Western boundary of coal block area was also simulated using the designed cross sections. The cross sectional area of the diverted Nala were computed using Manning's formula for different year return period flood. Optimization of these cross section were carried out by varying width and depth of the cross sectional area. Different trail runs were carried out with HEC-RAS model and results were compared with existing scenario. During these trail longitudinal slope were adjusted by providing five falls such that hydraulic aspects under diverted condition are same as those in existing condition. Optimum trapezoidal section was found to be of width 32m and depth 4.5m. The side slope was kept as 1: 1.5. Tominimize the mining area involved in diversion plan and to reduce seepage, the channel was proposed to be a lined section therefore the value of Manning's 'n' was selected as 0.020 under this scenario and was designed for the same. The 25, 50 and 100 year return period floods were taken as the upstream boundary of the model and normal flow condition as the downstream boundary

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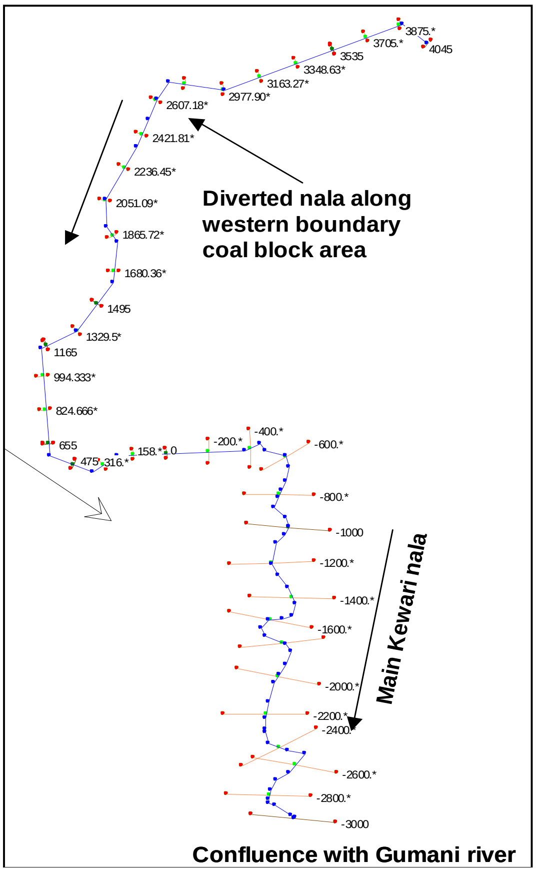

Fig.5. Schematic Diagram of Diverted KewariNala Reach Under Study (Scenario II)

7. Results of Model Studies

After preparing the required input data files for different scenarios HEC-RAS model was run. A number of model inputs and parameters as mentioned above were adjusted for better representation of model results. After successful HEC-RAS run, output files were obtained.Figure 6 shows predicted water level profiles for KewariNala reach for scenario I under existing condition. The results of predicted water levels along KewariNala reach under scenario I are for peak discharges corresponding to different year return period rainfall. Model simulations were taken to predict water levels and assess the sufficiency of the designed cross sections along diverted KewariNala reach (scenario II), using the developed model for the peak discharges corresponding to 25 year, 50 year, 100 year return period rainfalls as upstream boundary condition. Peak discharge from Nala 1 & 2 was added at appropriate location in the model under scenario II. The predicted water level profiles for diverted KewariNala reach are shown in figure 7. It could be seen from the Figure 7 that under diverted condition scenario II maximum flood levels are well confined within the designed cross sections and no spilling of flow over the banks. It was also seen from the results of mathematical model that hydraulics aspect such as water levels, velocities, discharges etc. for the common reach underexisting and diverted condition of KewariNala of the coal block area uptoGumaniRiver were found to be practically same for all the three peak flood events.

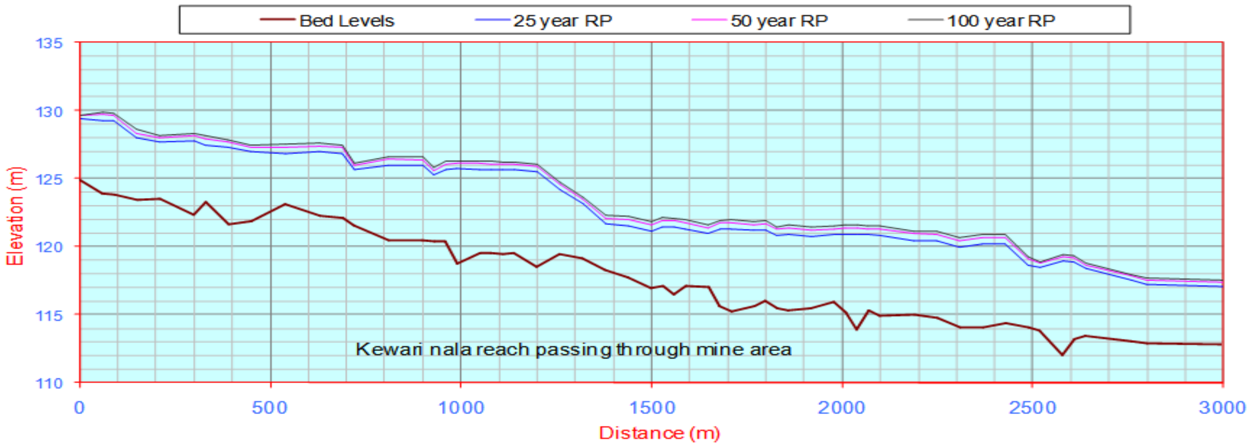

Fig.6. Longitudinal Section of KewariNala Showing Water Levels Under Existing Condition (Scenario I)

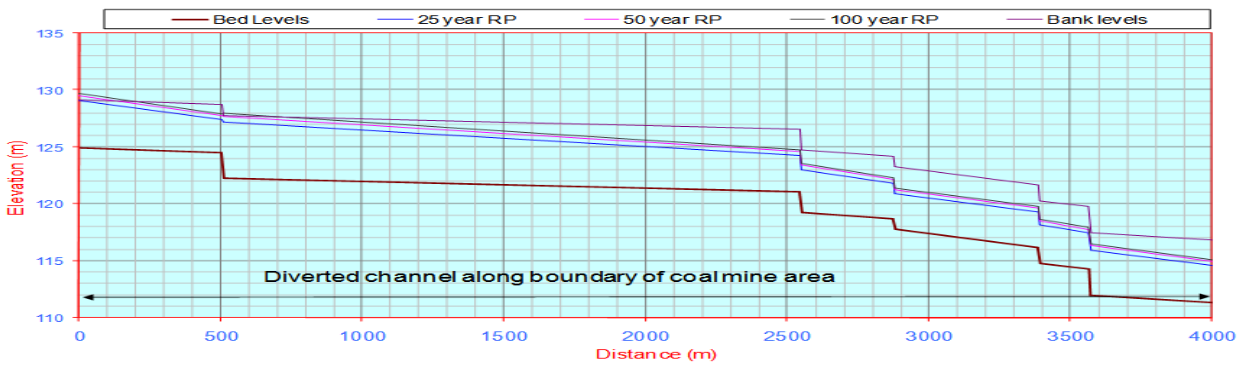

Fig.7. Longitudinal Section of KewariNala Showing Water Levels Under Diverted Condition (Scenario II)

The simulated output results under scenario I & II were compared at entry and exit points of the diversion channel. Table V shows comparison of predicted water levels at two locations for scenario I & II. The predicted water levels for 100 year return period (RP) at entry point of diversion under scenario I and scenario II were 129.68m and 129.72m respectively. Similarly, at the exit point under scenario I and scenario II were 117.70m and 117.24m respectively. Like-wise for 50 year RP these values at entry were 129.61m and 129.52m, at exit were 117.55m and 117.27m. . For 25 year RP these values at entry were 129.44m and 129.08m, at exit were 117.23m and 117.13m respectively. These comparisons reveal that existing verses diverted condition displays a good level of agreement.

Table 5. Comparison of Water Levels for Pre and Post Diversion Condition

Location	Predicted water levels (m) for peak discharges					
	100 year RP		50 year RP		25 year RP	
	Scenario I	Scenario II	Scenario I	Scenario II	Scenario I	Scenario II
Entry	129.68	129.72	129.61	129.52	129.44	129.08
Exit	117.70	117.24	117.55	117.27	117.23	117.13

8. CONCLUSION

The mathematical model study results for diversion channel of KewariNala along the boundary of coal block area indicate thatthe predicted water levels along diversion channel are well confined within the banks of Nala for peak discharges. It was seen from the results of mathematical model studies that there was no significant change in water regimes under existing and proposed diversion condition, for the common reach of KewariNala in the downstream of the coal block area up to Gumani River [15].

Thevast reserve of coal available in India is required to be taped economically to achieve the energy requirements of this developing country. In spite of numerous environmental and other problems, the diversion of Nalas become sometimes inevitable when huge reserve of coal is available beneath them. In such circumstances the approach described in this paper is a guideline to safeguard the hydrologic regime of the upstream and downstream of the mining area undisturbed. The hydrological and hydraulic models described in this paper could be applied for any such diversion management problems.In this paper One Dimensional Mathematical model approach had been adopted. For more refinement of result, 'Two Dimensional Mathematical model' can be adopted for future work or extension.

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