# MODELLING THE SEEPAGE FROM CHASHMA JHELUM LINK CANAL AND REHABILITAION OF THE WATERLOGGED AREAS

By

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**ABSTRACT**
Reliable estimates of seepage loss quantities from canals become crucially important while designing any water management activity in the area of interest. Variation of groundwater levels with respect to canal water level along the length causes drastic variation in canal seepage rates at various locations. Chashma Jhelum Link canal with influent and effluent behavior at upstream and downstream reaches respectively, poses a major challenge for seepage loss measurement using conventional methods e.g. current metering. Keeping in view these difficulties, Groundwater Vistas finite difference groundwater model (MODFLOW) was used for developing a 3-D, steady state groundwater model of the area surrounding the CJ Link canal. The model was run at 100, 75, 50, 25 and 0 % of full capacity of the C-J Link Canal, with the purpose to evaluate seepage behavior of the canal. Most of the results have been interpreted for the 100% capacity of the Link Canal in the form of water balance, seepage rates, groundwater elevation contour map and flow directions. The model has also shown standing water in the form of flooded cells where the water stands above ground surface. The C-J Link Canal at its full supply level, is gaining water from the aquifer from RD:77+069 to RD:136+000 @81.87 cfs and is losing to groundwater from RD:136+000 to RD:260+000 (model boundary) @282.51 cfs.

## 1 INTRODUCTION

Seepage is defined as the loss of water through the wetted area of bed and banks of a canal. Seepage from channels is dynamic process that is complicated by a variety of factors; soil type and permeability, sedimentation, erosion, fluctuating groundwater and canal water levels along with periodic filling and drying up of the canals. Important hydraulic characteristics influencing channel seepage include: water depth in channel, depth to groundwater and channel wetted perimeter. The most variable and important factor being the head difference between the water level in the canal and the watertable in the adjacent lands. Given that all other factors are constant, the two general situations depending upon groundwater level with respect to canal water level are as under;

Condition A: The watertable slopes away from the water surface in the canal and becomes horizontal at greater distances. In this case the seepage rate is related to the head difference between canal and groundwater levels.

Condition B: The watertable is well below the canal water level. In this case the change in watertable level does not have any impact on seepage rate.

According to a study in Australia by ANCID (2000), seepage losses increase as the difference between water level in the channel and watertable increases. When this difference is approximately five times or more than the surface width of the channel, seepage losses reach an upper limit.

### 1.1 *Past Seepage Studies*

A reliable estimate of seepage loss quantities from canals become crucially important while evaluating performance of an irrigation and drainage scheme. Several studies have been conducted to measure seepage losses from irrigation canals in Pakistan for different sizes of canals and in different parts of the country (Patten et al. 1963, USBR 1989, NESPAK 1991, Dukker et al. 1994, Khan et al. 2001 and Bodla et al. 1998). A review of seepage studies shows that the researchers have often used different methodologies to estimate the seepage losses in

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the Indus Basin. The main objectives in these studies were to assess the actual performance of the canal system, effectiveness of the lining or to identify the canal reaches prone to excessive seepage.

Charles (1963) reported that seepage losses from unlined canals in Pakistan, are normally assumed as 210 mm/day (8 cfs/msf) of the wetted area. Patten et al. (1963) analyzed the data of seepage losses of 70 canal reaches and developed a general formula for estimating seepage on the basis of discharge as under;

$$S = 0.03\ Q^{0.71}$$

Where Q is the canal discharge and S is canal seepage in cfs. The losses were measured for different soil types and under different watertable conditions in Punjab, Pakistan.

Dukker et al. (1994), using inflow-outflow method measured canal seepage for the Lower Gugera branch canal for the reach RD 65+000 to 171+000. Seepage losses were 460 mm/day (1991) and 250 mm/day (1992). It was concluded that groundwater levels have significant influence on seepage losses; i.e. losses for 1991 were about double the losses for 1992 as a result of depth to watertable decreasing from 3.25 m to 2.45 m respectively. Later Bashir et al. 1997 applied MODFLOW groundwater model for assessment of Lower Gugera Branch Canal seepage (RD 170+450) and estimated it to be 32.42 mm/day (1.23 cfs/msf) at a discharge of 53 $m^3$/day, when the watertable was only 1.5 m below canal bed and 2 m from NSL. This shows a drastic decrease in seepage losses as a result of shallow groundwater levels in the surroundings.

Siddique et al. (1995) measured seepage losses in CRBC canal by inflow-outflow method and were reported to be 126, 121, 100, 84 and 63 mm/day during 1990, 1991 1992, 1993 and 1994 respectively for the upper reach of the canal. While for the same canal, Ittfaq et al. (1998) applied modeling approach to estimate seepage losses. The losses were estimated to be 46.8 mm/day during the period of March 1995. Similarly Basharat and Hafeez (2002) also applied MODFLOW groundwater model for seepage estimation from the most seepage prone reach of Pat Feeder canal in Balochistan province and estimated it to be 35 mm/day (1.336 cfs/msf) for a canal discharge of 142 cumecs. Groundwater level in this case was 3 meter below the canal bed.

The ponding method is considered to be the most accurate means of measuring seepage losses as searched by shahid et al. 1996 (Robinson 1981, Hotes et al. 1985) and stated by Weller and McAteer 1993 and Bodla et al. 1998. However, the method is only suitable for measuring seepage in small channels.

IWASRI in collaboration with ISRIP and Punjab irrigation Department (PID) conducted seepage tests using ponding and inflow-outflow methods in order to conduct performance evaluation of FESS canal lining project (Bodla et al. 1998). Five ponding tests conducted in 1995 on four selected channels of the project indicated seepage rates ranging from 33 to 49 mm/day (1.25 to 1.86 cfs/msf) except on one channel (1L/3R Jourkanwala minor) where a seepage rate of 113 mm/day (4.28 cfs/msf) was observed. This higher seepage rate owed to greater depth to watertable (over 10 ft) as compared to other channels (2 to 5 ft). In order to confirm these low seepage rates another set of 25 number prelining ponding tests were conducted. These additional tests indicated average distributary seepage rates ranging from 37 to 70 mm/day (1.40 cfs/msf to 2.65 cfs/msf) except the one (1L/3R Jourkanwala minor) indicating higher seepage of 87 mm/day (3.31 cfs/msf) due to higher depth to watertable (10.2 ft). Inflow-outflow tests (14 No.) were also conducted on these channels for comparison purposes with ponding tests. These prelining inflow-outflow tests show average seepage rates ranging from 97 to 192 mm/day (3.7 cfs/msf to 7.3 cfs/msf). All these measurements were done on channels with discharge ranging from 4 to 307 cfs.

From the literature review it is concluded that inflow-outflow method gives higher seepage rates as compared to groundwater modeling approach and ponding method of seepage estimation. Whereas seepage estimates provided by groundwater modeling approach are even less than the ponding method.

### 1.2 *Chashma Jhelum Link Canal and seepage problem*

Among link canals, the Chashma-Jhelum (C-J) was constructed under the Indus Basin Treaty (IBT) during 1968-1971. It off-takes from the Indus River at Chashma Barrage and outfalls into the river Jhelum near Shergarh about 60 miles upstream of Trimmu Barrage. The link is an unlined earthen channel with a designed capacity of 21,700 cusecs. The link canal passes through the sandy area and the portion of the canal from RD 160 to RD 215 is in filling to varying degrees. As such, there is huge seepage from the link in this reach, which has turned the adjoining low-lying areas into waterlogged swamps. Waterlogging appeared in the area soon after the commissioning of the link canal in 1971. The low lying areas in Adhikot, Chann, and Rangpur villages and nearby seven big villages and small towns, with a gross area of 72,000 acres, came under its attack. Nearly 22,080 acres of the scattered agricultural land became severely waterlogged. The roads and large number of houses in the area were also damaged.

To overcome the problem of waterlogging, WAPDA installed 25 tubewells in Adhikot area in 1971 and 15 tubewells in Chann area in 1975 as anti-waterlogging measures for these villages. WAPDA also constructed during 1971-75, 25 miles of seepage drains, three miles of high level lined channels, five pumping stations and 21 (Nos.) lift pumps in the area. These measures, however, could not control the problem of waterlogging and salinity in the area, as the measures taken were not commensurate with the extent of seepage problem.

#### 1.2.1 C -J Link seepage measurement with inflow-outflow method

Pakistan Drainage Consultants (2000) has reported discharge measurements by ACOP/ISRIP undertaken from 1976 to 1992 using inflow-outflow method. Seepage loss measurements were done for two reaches i.e. Dullewala to Adhikot and Adhikot to Outfall. The discharge measurements showed quite a wide range in seepage results as shown in Figure 1.

As concluded by the consultants, the canal gains discharge by seepage from adjacent areas particularly when the discharge is below 10,000 cusecs. The inflow-outflow method used for these seepage measurements actually gives average gain / loss rates for the reach under observation. As shown in Figure 1, gaining / losing rate versus discharge of the canal do not

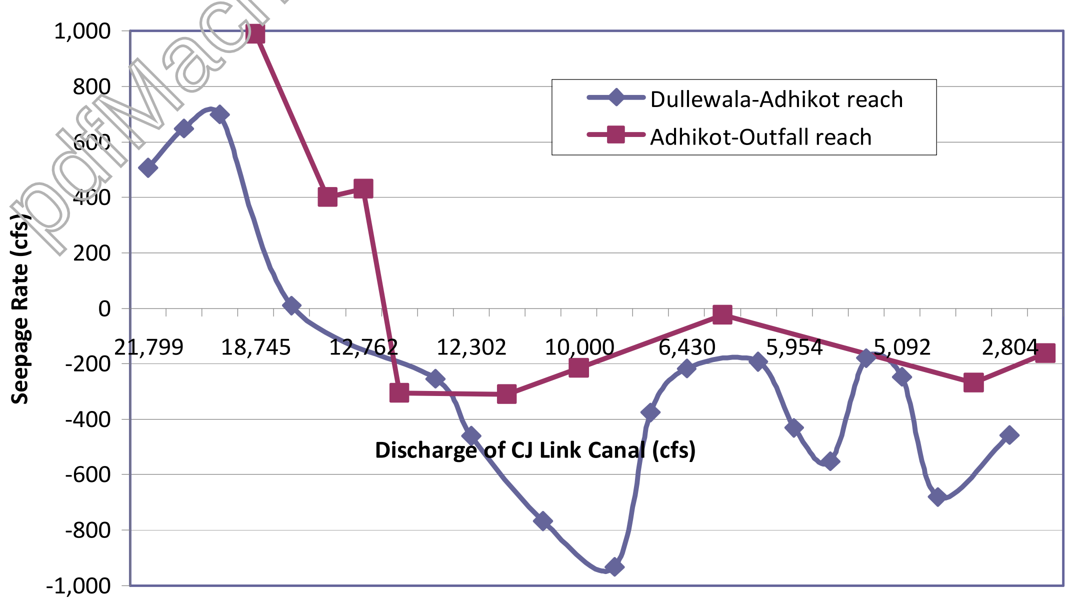


**Figure 1 Measures seepage rate for two reaches of C-J Link Canal using inflow-outflow method (as reported by Pakistan Drainage Consultants).**

interpret any relationship between the two parameters. This shows lack of reliability in using inflow-outflow method particularly where the reach under observation do not have solely losing or gaining behavior all along the reach.

### *1.3 Groundwater Simulation Models*

In recent years, numerous analytical and numerical groundwater models have been used to simulate the behavior of groundwater systems. However, for most cases of practical interest, the use of analytical methods is not feasible because of the heterogeneity of the aquifer parameters and irregular shape of the domain boundaries. Numerical models, which are in majority based on methods of finite elements or finite differences, have therefore been developed and are widely used for simulating aquifer systems with more complex initial and boundary conditions.

Among variety of numerical groundwater simulation models, MODFLOW is the most popular one. This is the modular three-dimensional finite-difference groundwater flow simulation model developed by the U.S. Geological Survey (McDonald et al., 1988). Since the publication of MODFLOW, various Graphical User Interface (GUI) have been developed by commercial vendors. Amongst these, Groundwater Vistas (GV) is a unique groundwater modeling environment for Microsoft Windows that couples a powerful model design system with comprehensive graphical analysis tools. It supports many codes such as MODPATH, MT3D, and PEST.

Owing to relatively more merits, now-a-days the applications of MODFLOW with GV for description & prediction of the behaviour of groundwater system have increased significantly. Hence, for this study the Groundwater Vistas (GV) with MODFLOW has been selected to simulate the behaviour of groundwater system in the C-J link area.

## 2 MODEL DEVELOPMENT FOR C-J LINK CANAL AREA

A three-dimensional groundwater model consisting of unconfined groundwater flow has been developed using Groundwater Vistas. Model results are presented using contours, shaded (color flood) contours, velocity vectors. Also detailed mass balance analysis is possible for any area of interest (ESI, 2007). The present model has been developed by using meter as length units and days as time units, thus flux rates for the model are in $m^3$/day. Keeping in view the data availability and time constraint, the model has been developed on steady state basis. In the watertable aquifers, water is derived from storage by drainage of pores, expansion of water and compaction of aquifer matrix. The governing equations incorporating Dupuit-Forchheimer assumptions applicable to such a situation for unsteady groundwater flow are as below;

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right) + R = S_{ya}\frac{\partial h}{\partial t}$$

Where R = R(x, y, z, t) is the recharge volume per unit aquifer volume at the point (x, y, z) at time t and have dimensions of $T^{-1}$, h = potential over the flow domain and $K_x$, $K_y$ = hydraulic conductivity in the x and y directions and $S_{ya}$ is specific yield of the aquifer. For steady state situation i.e. with no change in storage in the aquifer over the time period considered the above equation reduces to;.

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right) = 0$$

However, the variability in hydraulic conductivity was taken into account using zones digitized in the model, assuming same K values both for x and y directions.

## 2.1 Mesh Design

An area consisting of 53000 m, in length along the C-J Link Canal and 31600 m perpendicular to it, was modeled covering the C-J Link Canal from RD 77+069 to RD 260+000. The groundwater model consisting of 158 rows and 265 columns with 200 m uniform grid spacing, was developed and out of these, 527 cells were declared as no flow cells for ease in assigning inflow to the model from North-Western side. According to the above configuration, total area of the model becomes 167480 hectares excluding the no flow cells.

Subsoil investigations along C-J Link Canal alignment were carried out at planning stage of the Link Canal (WAPDA, 1972). These investigations revealed that the alluvial soils in the area extend to greater depths and that consist of poorly graded silt to fine to medium sand. However, soils of the upper strata vary from clay to silt and silty sand down to a depth of about 20 feet below the natural surface level. Therefore, keeping in view the lithology of the aquifer, two layer model was developed, with bottom of the aquifer as 372 m from top of the aquifer. Out of this, upper 7 m consisted of top layer and the remaining 365 m as the bottom layer.

## 2.2 Layer Elevations

In order to define top and bottom levels of above mentioned layers, the Shuttle Radar Topography Mission (SRTM 2000) data was used. The data consisted of pixels (90 m resolution) in raster format having elevation values as integers in meters. The data was processed in ArcMap software for removal of dips and spikes and converting it to point format. The top surface of the model was developed by importing the above data in Groundwater Vistas software. For developing the bottom levels of Layer 1 and Layer 2, 7 m and 372 m respectively were subtracted from the top elevations of Layer 1.

# 3 AQUIFER AND OTHER PARAMETERS

## 3.1 Hydraulic Conductivity Data

Hydraulic conductivity is an important parameter for model calibration. Unfortunately, neither any aquifer test nor any hydraulic conductivity test was performed in the past within the selected model domain. To tackle the problem, pump-out tests were carried out in shallow groundwater areas as described below. Data of aquifer tests already conducted at and around model boundary was utilized for aquifer characterization.

### 3.1.1 Upper layer

Pump-out tests were carried out by IWASRI at nineteen locations in the model area. These values of hydraulic conductivity (K) ranged from 0.064 to 9.192 m/day. Nine hydraulic conductivity zones were digitized for upper layer in Groundwater Vistas based on the above values. K values ranging from 0.5 to 9.12 m/day were finalized after calibration.

### 3.1.2 Lower layer

Lateral permeability data was available from aquifer tests carried out in the area between 1954 and 1963 by WASID (Bennett et al, 1967) at five sites mostly in the near vicinity of the model area. The lateral permeability values for these tests ranged from 50 to 116 m/day. Keeping in view the location of the aquifer tests, four zones of hydraulic conductivity were digitized ranging from 50 to 95 m/day. However, vertical hydraulic conductivity values were not available. So, the values for horizontal permeability were reduced by half and used as vertical permeability.

The model being steady state, does not require other aquifer parameters such as porosity, specific yield etc.

## 3.2 Field Irrigation and Rainfall Recharge to Groundwater

### 3.2.1 Watercourse and field irrigation losses

According to the report of Directorate of Land Reclamation (DLR) of Provincial Irrigation Department (Ali et al, 2002) the water allowance of Thal Canal is 3.8 cusecs per 1000 acres on perennial basis at watercourse head. Assuming that the distribution system runs 80% of the time, with this scenario, field application of water depth comes out to be 1.8385 mm per day.

Assuming 40% of this to be recharging to groundwater, the recharge to groundwater from irrigation (field application and watercourse losses) comes out to be 0.7354 mm/day. The most of the area falling within the model domain is with out irrigation and the canals mostly irrigate in the form of scattered strips along their alignment. To differentiate between irrigated and non irrigated areas, satellite images were used. Irrigated areas were digitized in the form of polygons keeping in view the canal alignments and vegetation cover which was well differentiable when compared to barani areas.

#### 3.2.2 Rainfall losses

Rainfall as recorded by IWASRI at Adhikot for the year 2007-08 (May to April), is 574 mm per year. The rainfall data all over the country shows that this was comparatively a wet year. So, it has to be adjusted using previous years rainfall data. As a result, 450 mm rainfall per year was adopted and 25% of this recharging to groundwater (owing to sandy nature of the top soil), a recharge rate of 0.308219 mm per day was calculated. Therefore, two recharge zones were digitized in the model and following recharge rates were used there in;

) For irrigated areas, adding irrigation as well as rainfall recharge, the total recharge to groundwater comes out to be 1.0436 mm/day.

) For barani areas, a recharge rate of 0.308219 mm per day has been used.

### 3.3 Recharge from Irrigation Network

The irrigation system (up to minor level) falling within the model domain was digitized from the SPOT Satellite images available for area after geo-referencing. The hydraulics data about these channels regarding full supply level (FSL), bed level, wetted perimeter were obtained from Punjab Irrigation Department (PID). The above information at all change points were composed on hard copy map and entered in the model using river package. River package is special form of the head-dependent boundary condition in which the model computes the difference in head between the boundary and the model cell where the boundary is defined. The head difference is then multiplied by a conductance term to get the amount of water flowing into or out of the aquifer. In a river boundary, MODFLOW performs an additional check before computing flow rates. If the head in the model cell is below the bottom elevation of the river boundary, the difference in head is computed as the river stage minus the river bottom elevation. This causes flow rates to reach a maximum value when an unsaturated zone exists beneath the boundary. River boundaries are used where a surface water feature partially penetrates a layer and can both remove/add water from/to aquifer.

### 3.4 Recharge from Chashma-Jhelum Link Canal

For representing Chashma-Jhelum Link Canal in the model, again the river package was used with data regarding FSL, bed Level and wetted perimeter as collected by the ISRIP (2008) of WAPDA during the condition survey carried out for the link canal. The river package allows the water to seep from the river boundary to groundwater when the FSL is higher than the groundwater level in the cell immediately below the river cell and vice versa. Therefore, the river package in the model has enabled to locate the cells in which C-J Link is gaining or losing along with the rates. Conductance values were adjusted during model calibration by varying K values of canal bed material.

### 3.5 Evapo-transpiration

Pan evaporation data of Noorpur Thal is being collected by Hydrology and Research Directorate of WAPDA. Noorpur Thal is a tehsil town of Khushab district and located about 20 Km from the C-J Link canal towards south. The model was calibrated for the month of May 2007. So, the monthly Pan Evaporation values of May for the available years, i.e. 1999, 2002, 2004, 2005 and 2006 were averaged. By applying pan coefficient of 0.7, a value of 6.65 mm/day was obtained. This value of 6.65 mm/day was used in the model for the top surface with an extinction depth of 1.25 m. This low extinction depth, was adopted due to sandy nature of top soil in the area.

### 3.6 Groundwater Pumping by Farmers

Large scale groundwater pumping is being carried out by farmers in the area, particularly in irrigated areas. To estimate this pumpage a survey was carried through filling out a questionnaire consisting of number of tubewells, their pumping hours along with discharge capacity on water course basis for irrigated areas only. These estimates were converted to distributary command basis and the resulting pumpage was applied to the model in respective canal commands uniformly with pumping rates from 800 to 1500 $m^3$/day. This groundwater pumping was adjusted very minutely for the purpose of model calibration. For barani areas, no groundwater pumping estimates were available. Therefore, during model calibration tubewell pumpage was added in barani areas too until the model calculated and field observed groundwater elevations were matched. The pumpage being carried out by public tubewells on both sides of the C-J Link Canal for lowering the groundwater near Adhikot and Chann areas was also added based on the condition survey as carried out by ISRIP (2008) with regard to location and discharge of the tubewells.

### 3.7 Regional Groundwater Flow

The regional groundwater flow coming into or going out of the model area can be handled in the model by a variety of different ways, i.e. by using General Head Boundary package of the Model if the groundwater elevations out side the model are available or by allocation of constant flow rates in the form of tubewells at the model boundaries. To start with, watertable elevation contour map for the month of June 2007 was prepared and used to delineate boundaries in which groundwater exchange with the model domain is taking place.

Regional groundwater flow is entering the model domain from Northern side of the model, i.e. upper left corner of the model. The regional groundwater is going out of the model through Southern side, particularly from those areas which are being served by Dullah Branch irrigation system. The groundwater is also flowing out of the model area from the Eastern side of the model towards River Jhelum. To handle above inflows / outflows in the model, recharging / discharging wells were installed in the model along these boundaries. The flow rates of these wells were adjusted until the model simulated groundwater elevations were matched with the field observed groundwater elevations along these boundaries during successive calibration runs.

## 4 MODEL CALIBRATION

In total, 170 observation wells are available in and around the model area including 109 observation wells installed for modeling study. Ninety, out of these 109 observation wells, were installed in the from of 15 transacts consisting each of 6 observation wells (three on each side of the canal) within the intended model domain. Observation wells survey regarding location and reduced levels with respect to mean sea level was carried out by Faisalabad Survey Division of Planning and Investigation (P&I) Organization of WAPDA. The observation wells were displayed in the GIS using XY coordinates from this survey. The wells wrongly displayed were adjusted according to their actual locations. With regard to data screening about reduced levels, the groundwater elevation profiles were plotted across the link canal for the 15 transacts of wells installed along the C-J Link Canal. The wells showing irregular groundwater elevations with respect to adjacent wells and C-J Link Canal water level, were screened out from the list to guide as target values for model calibration. As this kind of check for finding any leveling errors was not possible for the observation wells located away from the canal, so screening out was not done for the rest of the observation wells.

### 4.1 Calibration Targets

After screening of the observation wells as described above, total 128 targets, consisting of observed water levels, were added to the model for calibration purpose. These targets consisted of water level elevations for the month of May 2007 for wells along the canal and June 2007 for wells located away from the canal (data of wells away from C-J Link Canal was not available for the month of May 2007). These targets were divided in two Groups (1 & 2) for emphasizing more with respect to model calibration for observation wells installed close to the

C-J Link Canal. Group 1 consists of targets away from the canal and Group 2 includes targets close to the canal (at a distance of 125, 300 and 1000 m from the canal center line).

Model simulated groundwater elevations compared with corresponding field observed values for group 2 and group 1 are shown in Figure 2 and 3 respectively. The parameters evaluating the calibration of the model are given in Table 1.

Table 1 Parameter Values Obtained from the Model after Calibration.

| **Parameter** | **Parameter Values for** | |
|---|---|---|
| | **Group 2 (along the canal)** | **Group 1 (Scattered in the area)** |
| Residual Mean | - 0.0125 | 0.784 |
| Residual Standard Deviation | 0.506 | 1.212 |
| Residual Sum of Squares | 24.52 | 80.076 |
| Absolute Residual Mean | 0.366 | 1.212 |
| Minimum Residual | - 1.51 | - 1.829 |
| Maximum Residual | 1.67 | 3.783 |
| Observed Range in Head | 9.63 | 14.007 |
| Residual Standard Deviation/Range | 0.053 | 0.087 |

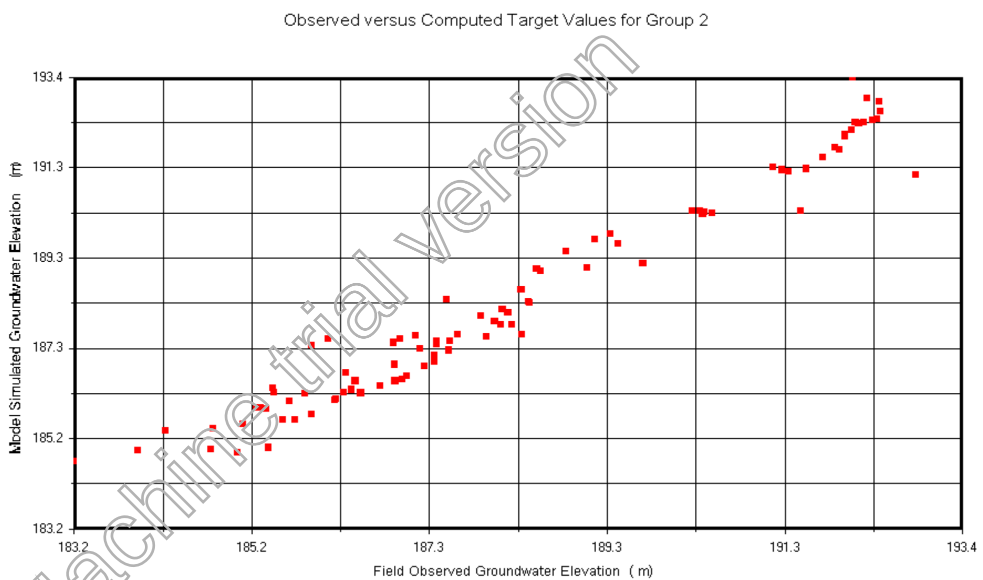





**Figure 2 Observed Versus Model Simulated Target Values of Groundwater Elevations Along C-J Link Canal**

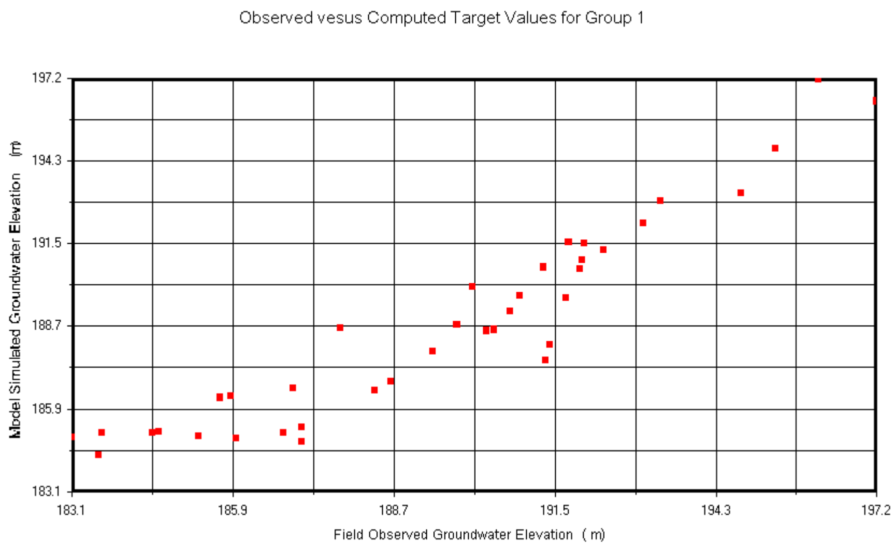



**Figure 3 Observed Versus Model Simulated Target Values of Groundwater Elevations away from C-J Link Canal**

## 5 RESULTS AND DISCUSSION

The model was run at 100, 75, 50, 25 and 0 % of full capacity of the C-J Link Canal, with the purpose to find out gaining/losing reaches of the Link Canal along with the corresponding gaining/losing rates. Most of the results has been interpreted for the 100% capacity of the Link Canal in the form of water balance, seepage rates, groundwater elevation contour map and flow directions. The model has also shown standing water in the form of flooded cells where the groundwater stands above ground surface. The model was also run with the scenario that the CJ Link canal does not exist. With this set up the model has shown standing water in Rangpur ponds and Ghangan village to the tune of 25% of the scenario when the CJ Link was running at full capacity. The results are discussed in detail as follows.

### 5.1 Water Balance for the Whole Model Domain

The model has the capability to interpret the results in many different possible ways which can best demonstrate/explain the interaction of surface water resources with that of groundwater resources in the model area. The most important of these, is water balance which can be obtained for the whole model domain or sub-areas of interest as well as separately for different boundaries inserted / used in the model. Based on analysis of water balance as provided by the model for full supply discharge of the link canal, the inflow / outflow rates are shown in Table 2 below.



Table 2. **Model mass balance on steady state basis with Chashma-Jhelum Link Canal flowing at its full capacity, i.e. 21,700 cfs (100% discharge)**

| Inflows to the Model (m$^3$/day) | | Outflows from the Model (m$^3$/day) | |
|---|---|---|---|
| Losses from irrigation system up to minor level | 1186693 | Evapo-transpiration | 1424497 |
| Irrigation application and rainfall losses in irrigated areas | 309740 | Pumping wells for irrigation | 780800 |
| Rainfall losses in Barani areas | 418230 | Outflow to Southern side | 146200 |

| | | | |
|---|---|---|---|
| Inflow from North-Western side of the model | 82000 | Outflow to Eastern side of the model | 136401 |
| C-J Link Canal | 691719 | C-J Link Canal | 200475 |
| Total: | 2688382 | Total: | 2688373 |

According to the results of the steady state model run, the C-J Link Canal while flowing at its full supply level, is gaining water from the surrounding aquifer from RD:77+069 (model boundary) to RD 136+000 @81.87 cfs and is losing to groundwater from RD:136+000 to RD:260+000 (model boundary) @282.51 cfs. The flow rates in model units ($m^3$/day) for the C-J Link Canal showing gaining/losing rates along its length as obtained for the model run at 100% capacity are shown in Figure 4. The model has shown very high gaining rates in the vicinity of node No. 4. These are the model cells located immediately below the Dullewala drop. The model has whereas Figure 5 shows cumulative gaining/losing rates by the C-J Link Canal along its length within the model domain.

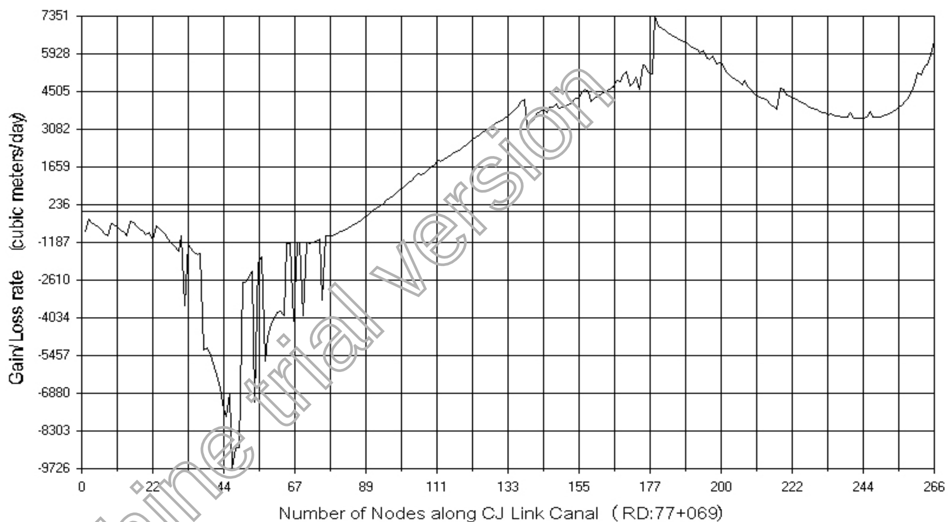



**Figure 4 Gain/Loss Rates by the C-J link Canal within the Model Boundary**

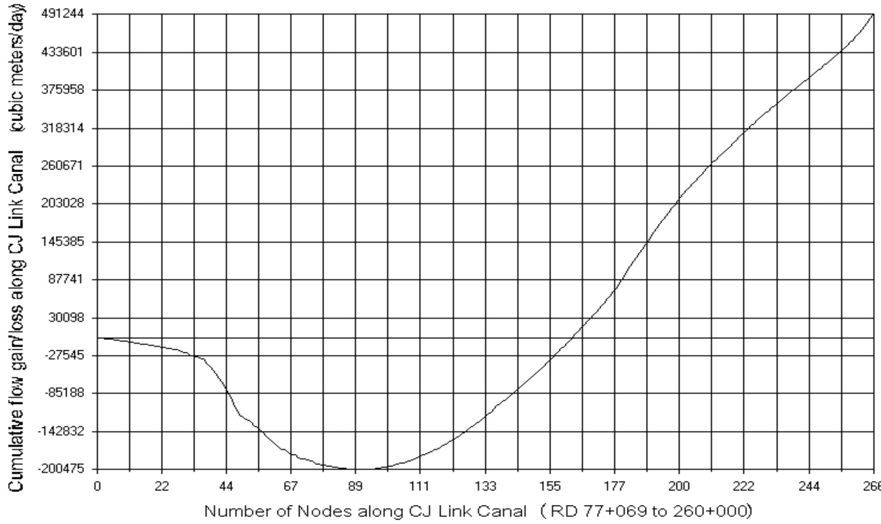
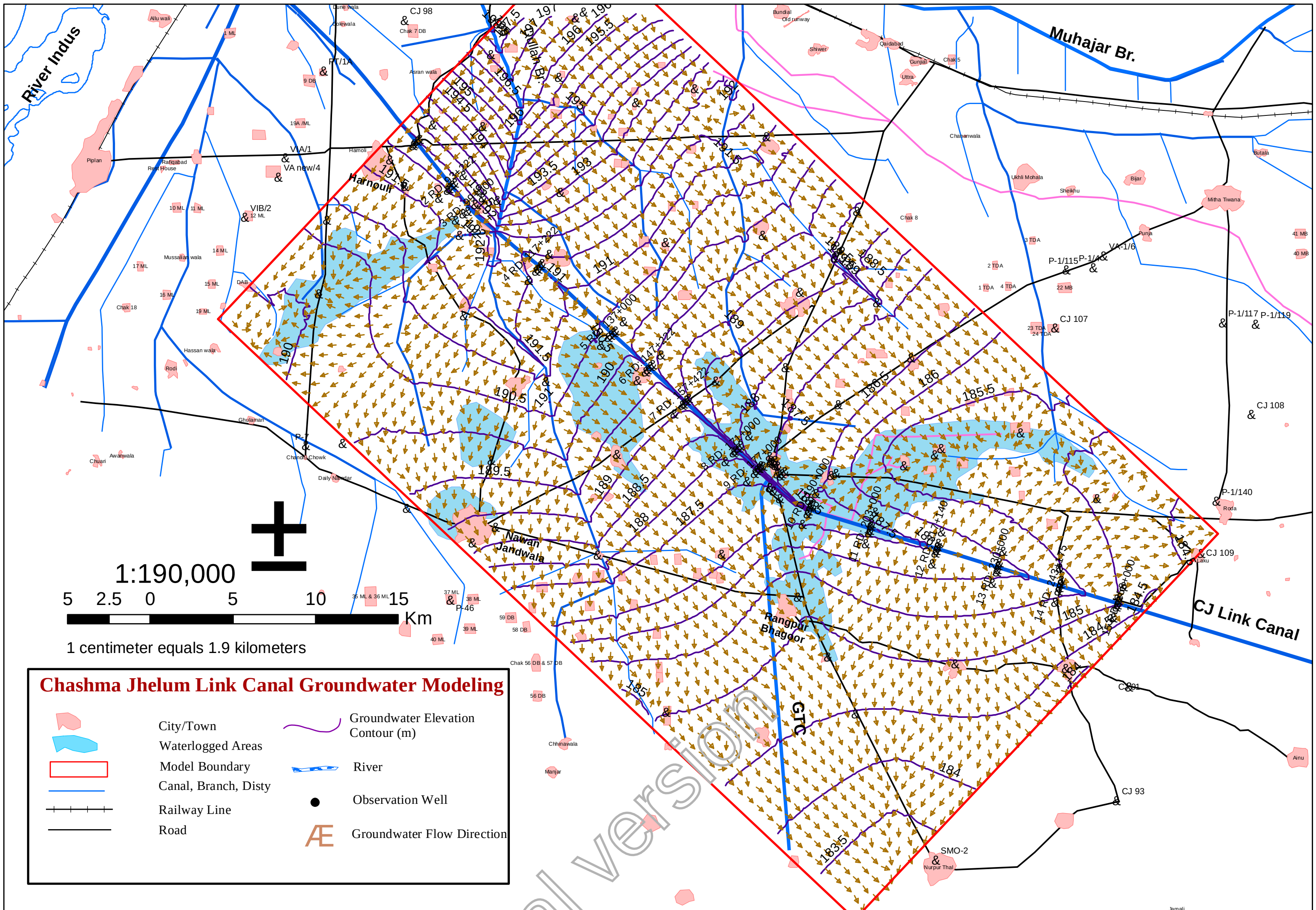



**Figure 5** **Cumulative Flux (Gain/Loss) along C-J Link Canal within the Model Boundary**

### 5.2 Groundwater Elevation Contours and Flow Directions at 100% Canal Capacity

The Figure 6 shows groundwater elevation contour map and groundwater flow directions as simulated by the model while canal flowing at its full capacity. According to the groundwater flow directions, contributions to the pond water on the left side of the C-J Link Canal is both from the Link Canal as well as from the recharge by the irrigated agriculture on the Northern side of the ponds. However, the contribution from C-J Link Canal seems to be very high in comparison to the other source of recharge. For the Rangpur ponded area, which lies on the right side of the C-J Link Canal, there is no source of recharge from irrigated agriculture in the pond surroundings. More-over, in the area to the southern side of the Rangpur ponds, people are normally pumping groundwater for barani agriculture as well as drinking purpose. The only source of recharge is rainfall in these areas. So, the recharge source for Rangpur ponds is the C-J Link canal only. Groundwater profile (as simulated by the model) drawn across the C-J Link Canal at RD:192+300 (Figure 7), also confirms above conclusions.

**Figure 6** **Groundwater Elevation Contours and Flow Direction in the Model Area (at 100% Discharge of C-J Link Canal)**


Chashma Jhelum Link Canal Groundwater Modeling
City/Town
Waterlogged Areas
Model Boundary
Canal, Branch, Disty
Railway Line
Road
Groundwater Elevation Contour (m)
River
Observation Well
Groundwater Flow Direction
1:190,000
5 2.5 0 5 10 15
Km
1 centimeter equals 1.9 kilometers
River Indus
Muhajar Br.
CJ Link Canal
GTC
Harnouli
Nawan Jandwala
Rangpur Bhagor
CJ 98
CJ 107
CJ 108
CJ 109
CJ 93
SMO-2
P-1/140
P-1/117
P-1/119
P-1/115
VA-1/6
VIA/1
VA new/4
VIB/2
PT/1A
P-46
Piplan
Mitha Tiwana
Nurpur Thal

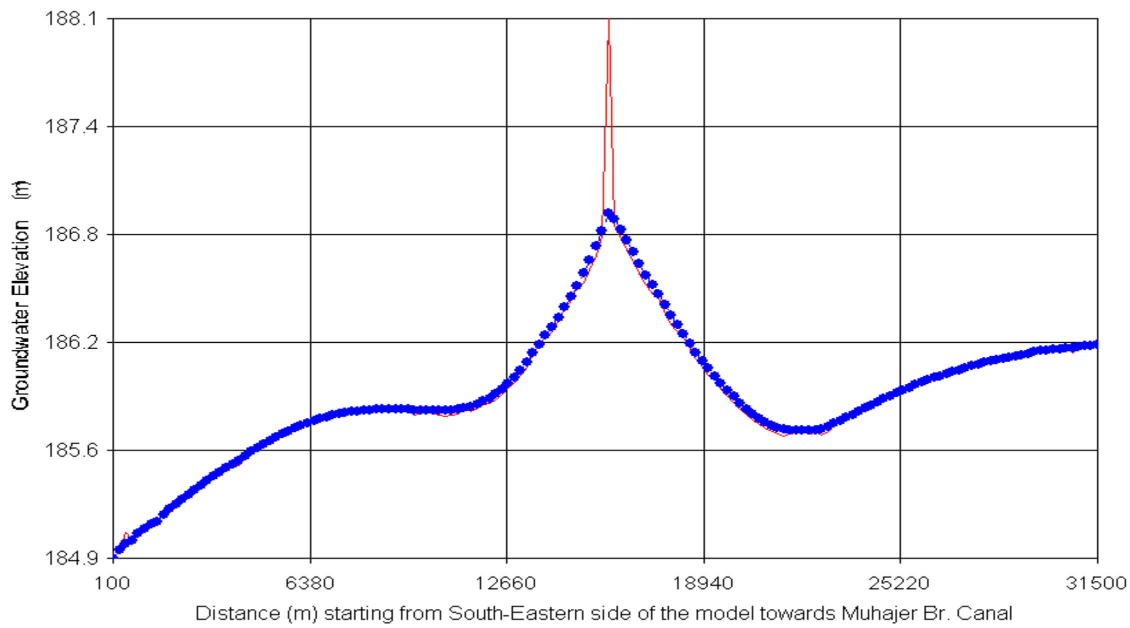



**Figure 7 Groundwater Elevation Profile Across the C-J Link Canal at RD:192+300**

**5.3 Seepage interactions of CJ Link at 75, 50, 25 & 0% of its Full Capacity**
The gain/loss rates of C-J Link Canal at 75, 50, 25 and 0% are as shown below:

- ✓ At 75% discharge, the canal is gaining water from the surrounding aquifer from RD:77+069 to RD 145+910 @130.21 cfs and is losing to groundwater from RD:136+000 to RD:260+000 (model boundary) @170.39 cfs.
- ✓ At 50% discharge the canal is gaining water from the surrounding aquifer from RD:77+069 to RD 158+078 @177.866 cfs and is losing to groundwater from RD:158+078 to RD:260+000 (model boundary) @73.728 cfs.
- ✓ At 25% of its full capacity, the C-J Link Canal is gaining water from the surrounding aquifer from RD:77+069 to RD 172+640 @214.213 cfs and is losing to groundwater from RD:172+640 to RD:260+000 (model boundary) @ 7.803 cfs.
- ✓ With no discharge in the Link, the canal is gaining water from the surrounding aquifer from RD:77+069 to RD:260+000 (model boundary) @ 269.526 cfs.

Summary of losing/gaining reaches of C-J Link Canal at various discharge capacities of the Link Canal (within the model domain) is given in Table 3 and in graphical format of the same is shown in Figure 8.

**Table 3 Losing/Gaining Rates along with RDs for Each at Different Discharge Percentages of C-J Link Canal.**

| Discharge Scenarios | Gaining Reach (RDs) | Total Gain for the Reach | | Losing Reach (RDs) | Total Loss for the Reach | |
|---|---|---|---|---|---|---|
| | | cfs | Cfs/msf | | Cfs | Cfs/msf |
| 0 | 77+069 to 260+000 | 269.526 | 3.40 | Nil | 0 | 0 |
| 25% | 77+069 to 172+640 | 214.213 | 5.18 | 172+640 to 260+000 | 7.803 | 0.21 |
| 50% | 77+069 to 158+078 | 177.866 | 5.07 | 158+078 to 260+000 | 73.728 | 1.67 |
| 75% | 77+069 to 145+910 | 130.210 | 4.37 | 145+910 to 260+000 | 170.39 | 3.45 |
| 100% | 77+069 to 136+000 | 81.870 | 3.21 | 136+000 to 260+000 | 282.51 | 5.26 |

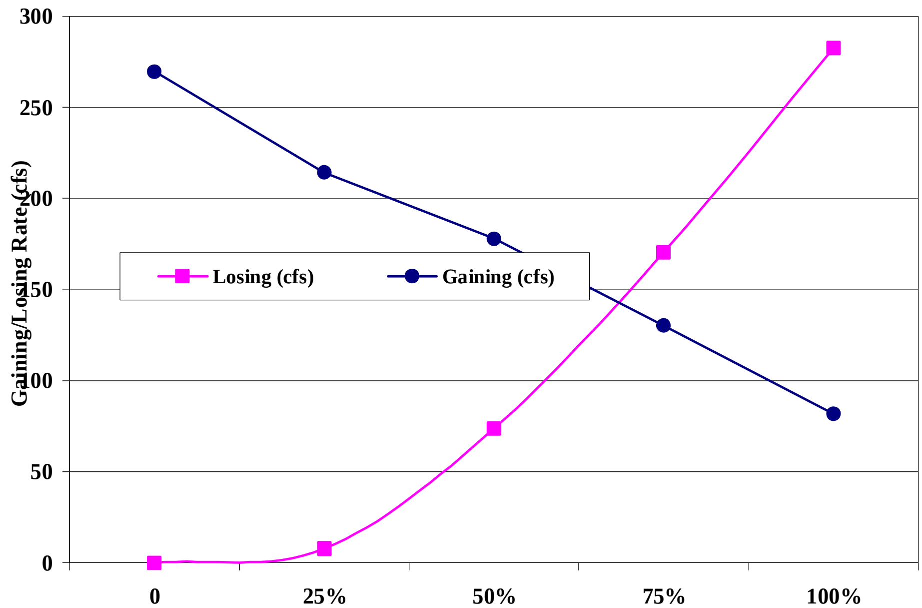



**Figure 8: Losing/Gaining Rates by C-J Link Canal at Different Discharges**

## 6 CONCLUSIONS AND RECOMENDATIONS

Groundwater modeling of the problem area has offered a very comprehensive conceptualization of interaction of surface and groundwater within the model domain. Quantum of seepage from the link canal and the reaches which are most seepage prone has also been made possible by the modeling. Testing of the possible technical interventions which can reduce the seepage from the canal and/or utilize the seeped water in a best possible way for economic and environmental uplift of the area can also be done with some additional efforts. For this purpose appropriate interventions need to be preliminarily designed and tested in the model separately or in combination with each other. These interventions may include lining of the most seepage prone reach of the CJ link canal, surface drainage by gravity of the waterlogged areas, installation of community tubewells for eradication of waterlogging and irrigation of adjacent high areas via the lined watercourses.

Following specific conclusions and recommendations are drawn from the study;

### *6.1 Conclusions*

- The CJ Link is a major source of seepage for the waterlogged areas in its surroundings.
- Waterlogged areas are depressions and the aquifer is deep/sandy, therefore no single solution i.e. lining/drainage expected to be technically/economically feasible. A combination of the solutions have to be preliminarily designed, model tested and cost estimated to select the economically best solution.
- Lining of the canal is expected to be very costly and drainage of deep depressions of Rangpur may still be needed.

### *6.2 Recommendations*

- Surface Drainage of the area along with community tubewells may be economically and technically most feasible solution. Drainage effluent is recommended for irrigation (gravity or lift) in adjoining un-irrigated areas.
- Surface drainage of the ponds seems to be possible as natural slope exists 1:1000 (on an average) towards Nurpur Thal. For this siphon under the C-J Link and carrier channel falling into escape channel of GTC is recommended.

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