Small Hydro Power: A viable option with special reference to Birthi Fall, Burthing Purdam and Phulibagar Kwiti Schemes, District Pithoragarh, Uttarakhand

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Abstract

Utilization of surface water is imperative in the present scenario. Water flowing in rivers, streams and streamlets blessed with appreciable discharge and hydraulic head carry enormous potential to generate hydropower, the demand for which has grown manifold over the years. With the plethora of problems associated with setting up of big hydropower projects in present times, the need for micro, mini and small schemes has increased substantially. Such schemes have low gestation period, low submergence problems, and practically no rehabilitation issues.

Small hydro potential (< 25 MW) in India is equal to 15000 MW. On a global scale, India stands fifth in terms of hydroelectric potential but a majority of the country's potential is yet to be tapped (about 88%). Northeastern region accounts for more than a third of the total hydro potential in the country but only 2% has been developed so far. The Ministry of New and Renewable Energy has created a database of potential sites of small hydro and 5415 potential sites with an aggregate capacity of 14305.47 MW for projects upto 25 MW have been identified.

With the economic liberalization, the Indian government also opened up the doors in 1991 to private companies for setting up of hydropower projects. Small and mini hydel projects have the potential to provide energy in remote and hilly areas where extension of an electrical transmission grid system is uneconomical besides other advantages.

This paper deals with the pertinent need to set up smaller hydroelectric schemes with emphasis on detailed case studies of three such schemes in the Kumaon Himalayas wherein despite site constraints, geological investigations have helped to arrive at the best

possible layout. In addition, surface water has been utilized to optimum advantage and the tail scheme has benefited from the discharge of the feeder scheme.

1. Introduction:

The problems related with setting up of huge projects namely submergence of populated lands, issues of rehabilitation, loss of precious flora and fauna, environmental degradation, environmental impact assessment and related issues have limited the growth of mega projects. The infamous Tehri Dam has been commissioned for hydro power generation but not without its share of unprecedented problems that came its way.

With the economic liberalization, the Indian government also opened up the doors to private companies for setting up of private hydropower projects. The government also came in favour of growth of more affordable schemes which could be developed with low gestation period and lesser hindrances. Instead of promoting isolated or stand alone hydro power schemes, the emphasis now is to adopt a Total Integrated Watershed Development of natural resources on micro watershed basis with preference for "Run of the River" hydro power schemes. Promotion of such scheme would lead to lower Geoenvironmental and socio economic stresses and opposition, less management costs, time overruns and better returns.

An estimated potential of about 15,000 MW of small hydropower (SHP) projects exists in India. The Ministry of New and Renewable Energy has created a database of potential sites of small hydro and 5415 potential sites with an aggregate capacity of 14305.47 MW for projects upto 25 MW have been identified. The major players include Himachal Pradesh (2268.41MW), Arunachal Pradesh (1333.04 MW), and Jammu and Kashmir (1411.72 MW).The installed capacity for SHP units reported a significant increase from 1909 MW as in March 2006 to 3300 MW in January, 2012, taking up SHP's share of the country's total installed renewable energy capacity to ~15%, however considerable potential still remains untapped.

The strategy is particularly applicable in Himalayan terrain, where there is immense power potential and lot of hydro energy is still untapped. The idea is to identify potential segments conducive to head and discharge utilization for hydro power. Small and mini hydel projects have the potential to provide energy in remote and hilly areas where extension of an electrical transmission grid system is uneconomical. Realizing this fact, the Indian government is encouraging development of small hydro power (SHP) projects in the country. The role of private sector for setting up of commercial SHP projects has been encouraged. Around 14 States in India have announced policies for setting up commercial SHP projects through private sector participation. Over 760 sites of about 2,000 MW capacities have already been offered / allotted.

The Western Himalayas in Uttarakhand can broadly be divided into the Kumaon and Garhwal, which have been the centers of deep rooted interest for the economic potential that they carry. Water flowing in these rivers is a nature's gift and harnessing its hydro potential is by far the surest way to contribute towards national economy. The Kumaon region in Uttarakhand is being seen as an upcoming potential in terms of hydropower.

Based at the interfringe of Middle – Higher Himalayas are three important examples of mini to small hydro power schemes namely Birthi Fall, Burthing-Purdam and Phulibagar -Kwiti HE Scheme which after having been identified, conceived and geologically and techno economically evaluated and investigated, are likely to be taken up for construction.

2. Project Features:

The Birthi Fall HE Scheme envisages construction of a trench weir across Bhelchhina Nala, a small tributary of Jakula *Nadi.* The scheme is proposed to divert water (0.96 cumec) through a 1.2 Km long steel piped/ open channel water conductor system to a surface power house near village Burthing to generate 1.0 MW (2x 0.5MW) of power by utilizing an available gross head of 156.2m. Geologically, the area exposes schists and gneisses of Central Crystalline Group. The Main Central Thrust (MCT) separates the rocks of Central Crystalline Group towards north with the rocks of Garhwal Group towards south. The appurtenant structures include trench weir, desilting tank, WCS, forebay, and a surface power house designed for overburden.

The *Burthing- Purdam HE scheme* located just downstream of Birthi Fall scheme is another run of the river scheme across Jakula *Nadi.* This scheme is partly within Central Crystalline Group of rocks represented by gneisses and schists and partly within carbonate rocks of Garhwal Group. The zone of MCT (?) cuts across the region slightly downstream of the weir site location. The scheme envisages construction of a trench weir near village Burthing to divert water (4.92 cumec) through a 1.4 Km long water conductor system to a surface powerhouse near village Purdam. The proposed scheme would generate 6.5 MW (2x 3.25MW) of power by utilizing an available gross head of 195m. Two layouts viz. Alt I and Alt.-II are under consideration. The trench weir site locations for two alternatives vary. Alt.-II, however, appears to be more feasible, considering the site constraints. The appurtenant structures include trench weir, desilting tank, water conductor system (steel pipe and open channel), forebay, penstock and surface powerhouse, designed for overburden.

The Phulibagar Kwiti HE Scheme is located downstream of Burthing Purdam HE scheme across Jakula *Nadi.* The site is occupied by Garhwal Group of rocks represented by carbonates (limestone, dolomite, quartzite). The scheme envisages construction of a trench weir near village Phulibagar to divert water (7.68 cumec) through a 1.3 Km long water conductor system to a surface powerhouse near Kwiti. The scheme would generate 5.0 MW (2x2.5 MW) of power by utilizing an available gross head of 98.0m. The appurtenant structures include trench weir, desilting tank, water conductor system (steel pipe and open channel), forebay, penstock and a surface powerhouse, designed for overburden.

3. Physiography:

Physiographically, the area of study is represented by mountain and valleys and a typically rugged topography. The prominent drainage Jakula Nadi joins Ramganga near

Tejam and has a total catchment area of 112 km^2 up to its confluence with Ramganga. The River Ramganga descends from an approximate elevation of 4000m above msl to its confluence with river Sarju at EL 456m. It is fed by Ramganga and minor glaciers, which originate at a height of about 6050m. It's major left bank tributary, Jakula Nadi descends from El 4100m and makes a confluence with river Ramganga at El 970m (Figure 1).

In accessible reach, the river Ramganga has a low to moderate gradient of about 2% whereas Jakula Nadi has a much steeper gradient of about 5%. The Jakula nadi has an average slope of 1 in 15. The approximate discharge of the river Ramganga at Thal is reported to be varying between 10-350 cumec.

4. Regional Geology:

The area of investigation exposes rocks of Central Crystallines and Garhwal Group. The Central Crystallines represent the oldest rocks exposed in Higher Himalayas and consist of gneisses, migmatites, psamitic and mica gneiss, calc gneiss, quartzite, marble mica schist and amphibolite. The rocks of Central Crystalline Group comprise *Dar* and *Nyu* Formations. The Dar Formation forms the basement in the area and is divided into *Bauling, Sela and Nagling* members.

The sequence of Garhwal Group comprises shale, slate, phyllite, quartzite, dolomite, limestone, magnesite, occasional calc slate and metavolcanics. The rocks of Garhwal group are represented by *Pithoragarh* Formation and *Berinag* Formation. The Pithoragarh Formation is divisible into lower and upper members. The Lower member comprises stromatolite bearing dolomitic limestone, calcareous phyllite, quartzite and marble. The Upper member consists of dark grey calcareous slate and limestone. Berinag Formation (=Nagnithank Formation) comprises quartzite interbedded with metavolcanics, gneisses and slate.

Quaternary sediments are represented by *Older and Newer Alluvium*. The *Older Alluvium* is characterized by *Older Terrace Alluvium* and *Older Glacial Deposit*. The Older Terrace Alluvium exposed is characterized by well sorted and rounded cobble and pebbles of gneiss and schists in highly oxidized sandy matrix. The Older Glacial deposit consists of angular to subangular assorted fragments of quartzite and gneiss embedded in the oxidized sandy matrix. *The Newer Alluvium* is classified into *Terrace Alluvium* and *Channel Alluvium*. The Terrace alluvium is characterized by angular clasts of gneiss, schists, amphibolites and limestone embedded in clayey matrix.

The Main Central Thrust delineates Garhwal Group of Rocks to the south from the Central Crystalline Group of Rocks to the north. While the Birthi Fall HE scheme lies totally within the rocks of Central Crystallines, the Burthing Purdam scheme lies partly within the two groups, whereas Phulibagar Kwiti scheme lies totally within the Garhwal Group of Rocks.

5. Site Geology and Geotechnical Discussions:

5.1 Birthi Fall HE Scheme:

The perennial 125m high Birthi Fall near village Burthing is a known tourist spot situated next to the road head connecting Tejam and Munsiari (Figure 2). The fall draws its water from Bhelchhin Nala dropping along the scarp faces of the rocks representing the Central Crystallines. Gneisses and schists are the main rock types having foliation dipping 14°-27° towards N351°- N020°. The layout of the scheme was originally proposed by the project authorities along the left bank slopes of river Jakula encouraged by an available head of ~230mts. The slope which apparently appeared feasible, on closer examination was found vulnerable to sliding. A zone of not less than 400m width along the lower contour elevations towards left bank of the river shows distinct signs of movement at close intervals. Indication can also be had from the fact that slide protection measures have been adopted, to arrest the downward movement (Picture 1). An overburden slide L1 (~40m x 20m) at the base of the hill near confluence of the nala with Jakula nadi is also observed. The settlements on this slope also showed signs of subsidence. The proposal was thus ruled out by the GSI.

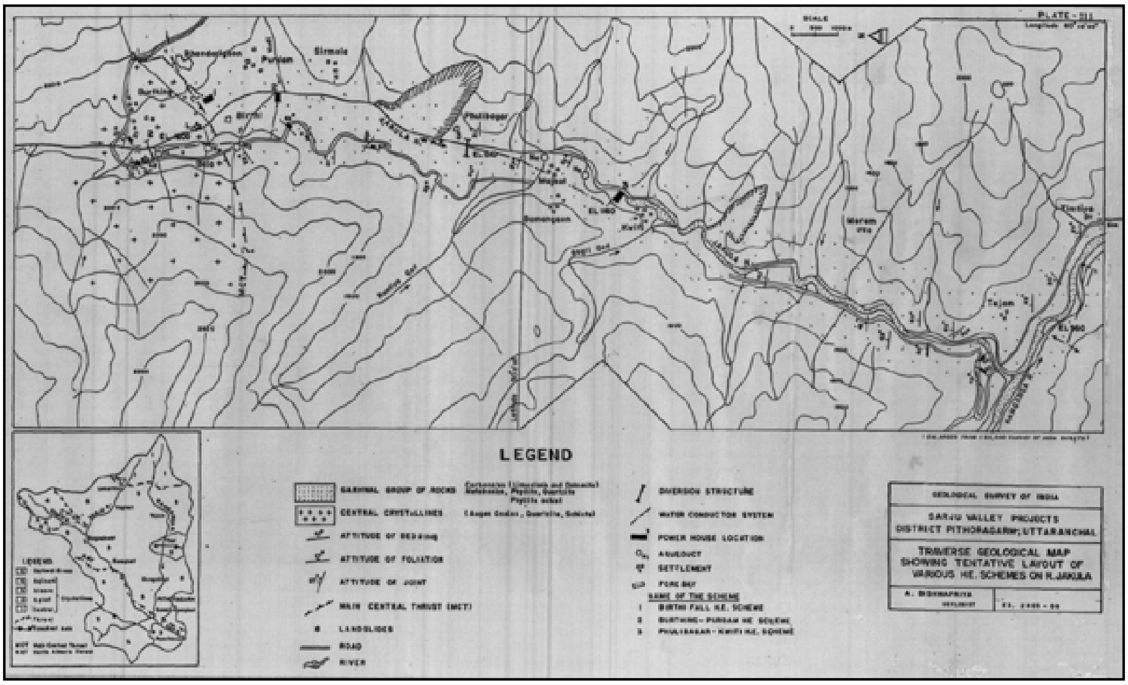
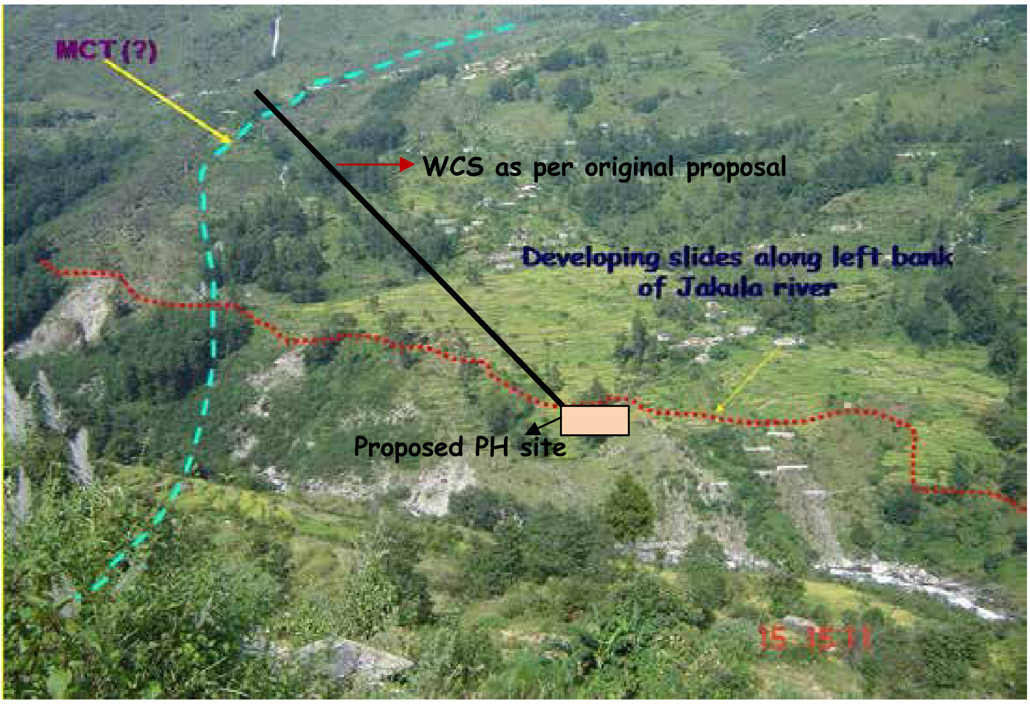


Figure 1 Traverse Geological Map showing layout of Birthi fall, Burthing Purdam and Phulibagar Kwiti HE Schemes on Jakula River

A modified Water Conductor System layout aligned along the base of the near vertical scarp face and a surface powerhouse on a raised terrace near village Burthing was suggested by the GSI. The near vertical rock face is fairly stable with no apparent geotechnical problems. The nala at the base of the scarp flows westerly and west south west after cutting across the motorable road head. Here, the left bank of the nala is under extensive overburden cover comprising large boulders (~3cubic m) of crystalline rocks

The right bank, however, has a vertical rock face close to the fall, which recedes from the nala as one move further downstream. Characteristically, the slopes can be categorized into overburden type towards the left bank of the nala, boulder covered along the course of the nala and typically terrace / overburden covered on the right bank.



Picture 1 The slide prone left bank slopes of river Jakula. In the backdrop is seen the Birthi Fall and the layout of the original proposal

5.1.1 The Diversion Structure:

The diversion trench weir is proposed 55m upstream of the bridge across Belcchin nala at El. ± 1785m. The width of the river at site is ~18m. The structure may have to be designed for overburden. The nala bed is strewn with large boulders of crystalline rocks which are stationary. No movement of the boulders has been observed. The right abutment consists of near vertical rock face representing hard and compact gneisses with intervening schist bands. The river bed and the left bank are completely covered by overburden consisting of big size boulders. The strike of the formation is east-west with northerly dips. The barrage axis is somewhat perpendicular to strike of the formation. The dips are into the hill and are hence favorable for the slope stability. The other sets of joints as observed in the area are described in table 1.

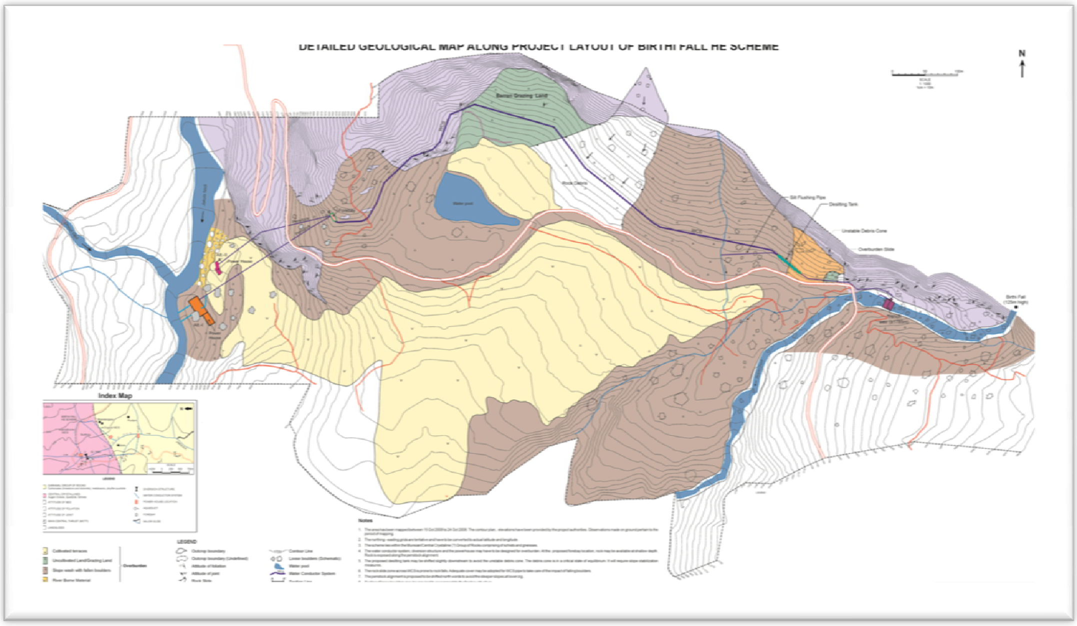


Figure 2 Detailed Geological Map along the project layout of Birthi Fall HE Scheme, District Pithoragarh, Uttarakhand.

Table 1
Joint Sets observed in Diversion structure Area

Joints	Dip Direction/Amount	Spacing	Continuity
J1	N351°- 020°/14-30°	2cm-5cm	long, +10m
J2	N93°-95°/31°-47°	50-450 cm	5-15m
J3	N304°-317°/66°-70°	1-5 m	15-30m
J4	N178°-190°/68°-83°	30cm-100cm	1.5-+5m

5.1.2 Intake:

The water from the trench at diversion site would be diverted into the WCS pipe which is aligned through the right bank of the nala. The WCS would initially negotiate hard crystalline rocks which would necessitate good anchoring and support. It may be difficult to execute a channel through the vertical rock face to accommodate the WCS pipe.

5.1.3 Desilting Tank:

The proposed desilting tank lies over a debris cone, which is in a critical state of equilibrium. It may not be feasible to place a structure in this reach. It is recommended to relocate the desilting chamber and shift it slightly downstream so that it is kept to the left bank of the *nala* flowing along the vertical rock face. The discharge of this minor gully may also be diverted. Cut and cover arrangement with some provision against impact of falling boulders may also be taken.

It is reported by the project authorities that the silt content of the scheme is almost negligible. Hence the necessity of the desilting basin may be reviewed. However, the same may be fully ascertained by examining the silt data of the stream for the last five years before a decision in regards to the matter is taken.

5.1.4 Water Conductor System:

About 70% of the 710m long water conductor system would be laid on overburden. The remaining 30% of the WCS is proposed to be founded on hard and compact Crystalline rocks. Since the rock is hard and compact, piped WCS with suitable anchors may be feasible all through instead of open channel. It would be advisable to keep the WCS pipe concealed to protect it from the impact of fallen boulders.

There is a prominent rock slide across the WCS. The WCS may have to negotiate the major slide debris which is prone to rock falls. However there is no evidence of sinking in this zone. In this zone, WCS pipes may be adopted with adequate cover to prevent it from the impact of falling boulders. Further it may be advisable to design the WCS in a way where replacement of pipes may be easy.

5.1.5 Fore bay:

The fore bay site is proposed on a stable overburden slope comprising large boulders in a sandy soil matrix. Moderate to large boulders are observed in this area. Some scaling and benching of these slopes may be required to prepare the fore bay foundation. Rock may also be available at shallow depth in the area.

5.1.6 Penstock:

The penstock slope is steep and partially occupied by overburden towards the upper road zig and by rock towards the lower road zig .The formations have foliation dipping N002°- N016°/ 12°-20°. Prominent sets of joint include (J1) N099°-N117°/ 38°-50°, (J2) N170°-200°/62°-80° and random occurring joint N280°/80°. The alignment crosses steeper slopes at the lower zig (El. ±1710m). Here the penstock alignment may have to be realigned by shifting it northwards closer to the road bend at the lower zig, thus avoiding the steeper slopes (Figure 3).

5.1.7 Powerhouse:

It is recommended that the proposed powerhouse site location be shifted northward on a flat terrace on the left bank of Jakula *Nadi.* This location depicted in the survey sheet may not be feasible as it falls exactly opposite to the confluence of Dhauli Gad and Jakula river. The new location can further be lowered to desired level to attain additional head.

The height of the terrace from the river bed is ~10-14m.The structure may have to be founded completely on overburden

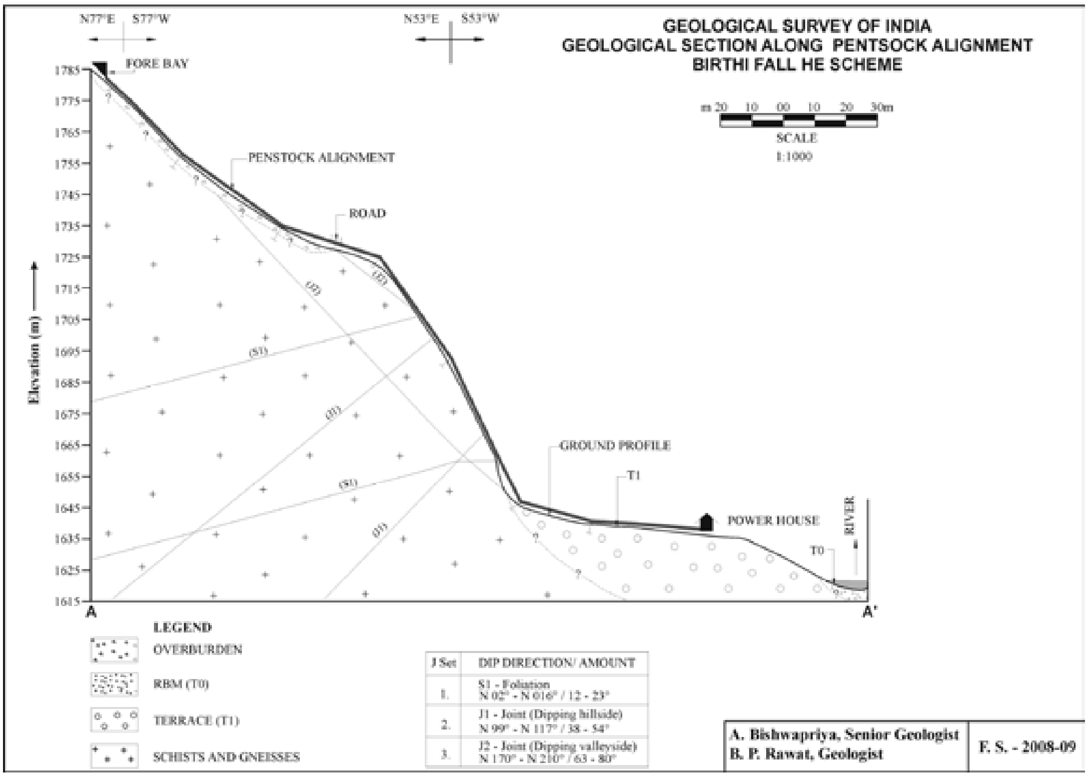


Figure 3 Geological section along Penstock alignment, Birthi Fall HE Scheme

5.2 Burthing- Purdam HE Scheme:

This scheme is partly within the Central Crystalline Group of Rocks represented by gneisses and schists and partly within the Garhwal Group of Rocks (Figure 4). The zone of MCT (?) cuts across the region slightly downstream of the weir site location. The effect of MCT can be had from the abundant strewn rock boulders scattered all along the hill slopes on the left bank.

Two alternatives of water conductor system are under consideration for the scheme. The Alternative -I has its diversion site at (El. ± 1615m) and Alternative-II has its diversion site at (El. ± 1586m). The geotechnical assessment of the two separate alignments is being addressed individually.

5.2.1 Diversion Structure-Alternative I:

The WCS with diversion site at (El±1615m) has been proposed by the project authorities. The site lies immediately downstream of the confluence of Dhauli Gad and Jakula The weir site is devoid of any rock and may have to be designed on a permeable foundation with a suitable cutoff. The width of the river at site is 15-20m. The gradient of the river at this site is high. Huge boulders of gneissic rock are observed at this location and near the intake. These may have to be removed in order to accommodate the diversion structure and the intake. There is a gradual slope on the left abutment though totally covered by overburden. The right abutment is also covered by overburden and loose boulders are seen strewn over the entire slopes. Flash floods have been reported in the region. In past, an existing bridge slightly downstream has been completely washed off and its remnants can still be seen. This aspect may be duly acknowledged. If the site is considered, proper keying/ anchoring of the weir, approach and tail apron may be required.

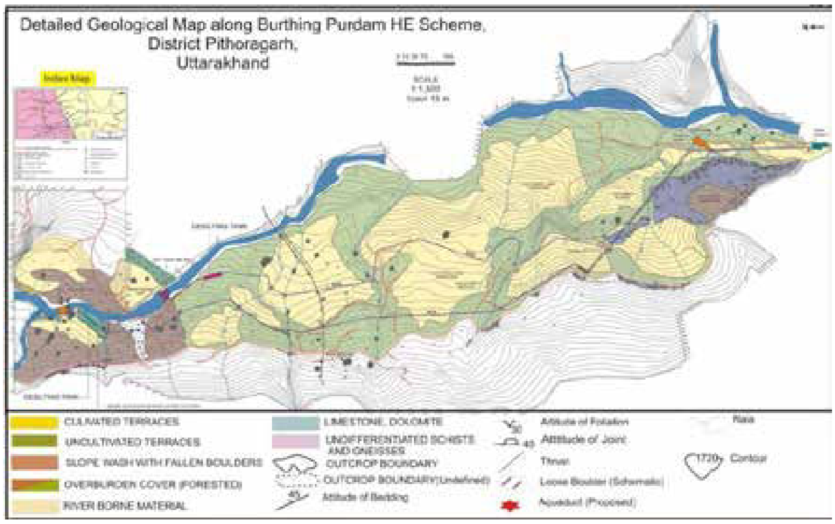


Figure 4 Detailed Geological Map along Burthing Purdam HE Scheme, District Pithoragarh, Uttarakhand.

5.2.1.1 Desilting Tank:

The proposed location of the desilting tank is under cover of dense scrubs and bushes. The site was thus not available for detailed observation. Slight seepage from the nearby gully has also been observed in this reach. There is slight erosion of the right bank in this reach due to river cutting.

5.2.1.2 Water Conductor System:

After the desilting tank, the WCS may have to negotiate a debris slide zone at the lower half of its shoot. Debris is spread over the entire realm of the slide. The lower $2/3^{rd}$ portion of the slide appear to be safe. The upper $1/3^{rd}$ portion is somewhat critical near the crown portion. The road head is providing a bench and further aggravation of the slide seems unlikely. It doesn't appear to be a sinking zone. The WCS after the slide zone, passes through loose overburden (slope wash) with moderate vegetation cover. Embedded boulders have also been observed in the area. The WCS thereafter passes through gentle slopes. It cuts across a *nala* N1 where it may have to be aided with an aqueduct. The WCS may have to negotiate a ridge kind of landform further downstream.

This may have to be negotiated with sharp bends that may not be possible through pipes and hence open channel for the reach may have to be provided.

5.2.1.3 Fore bay:

The fore bay site is proposed along the slopes next to the motorable road head. A small rock outcrop is exposed along the road section next to the fore bay location, however the structure may have to be designed for overburden. Some space may have to be created for the structure by creating a bench, as ready available space may not be present. The civil structure can be tied to the rock for stability, as rock could be available at shallow depth.

5.2.1.4 Penstock:

Around penstock alignment the rock (limestone and dolomite) have beds dipping 25-30° towards N300°- N312°. Prominent sets of joint include (J1) N020°-N025°/ 70°-75°, (J2) N110°-135°/70°-78° and (J3) N215°-240°/68°-80°. The dips are into the hill and are hence favourable for the slope stability. These sets have been observed in the limited exposures along the alignment. The penstock slope is moderate and it is aligned through cultivable fields on the left abutment. Intermittent exposures of dolomitic limestone may also be available along the alignment. At El±1426, a kink has been given to the alignment. Thereafter, it passes through the low lying terraces on the left bank and may have to be totally designed for overburden. As the alignment of the penstock passes through overburden, proper and deep anchoring of the penstock pipes may be required. The alignment crosses a gully where proper slope cushioning may have to be provided (Figure 5).

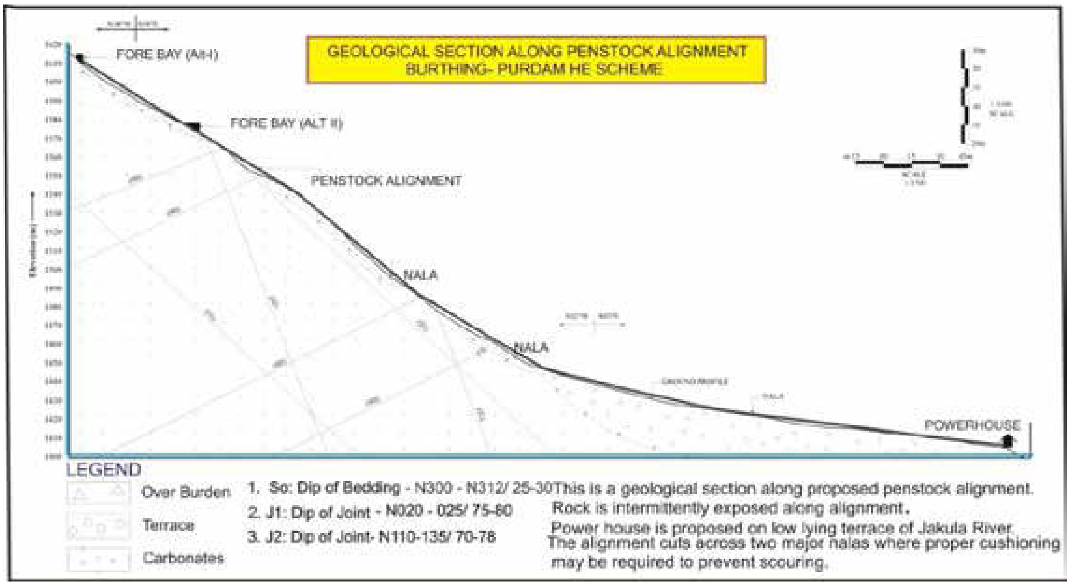


Figure 5 Geological section along Penstock alignment, Burthing-Purdam HE Scheme.

5.2.1.5 Powerhouse:

It is recommended that proposed powerhouse site location be shifted further downstream by about 260-270m as the present location lies exactly opposite to the confluence of Gadiyar Nadi and Jakula *Nadi,* hence the site may not be feasible. Shifting of the PH location may also result in overall gain in head of about 25m. The powerhouse structure may have to be designed for overburden as the area is devoid of rock exposures. Continuous rock line is available, north west of the powerhouse location.

5.2.2 Diversion Structure-Alternative II:

The diversion site at (El±1586m) lies ~330m downstream of the confluence of Dhauli Gad and Jakula *Nadi.* The weir site is devoid of any rock and may have to be designed on a permeable foundation with a suitable cutoff. The width of the river at site is 15-18m. The gradient of the river at this site is moderate. The slope is continuous with no appreciable break in gradient. There is a gradual slope on the left abutment though totally covered by overburden. The right abutment is also covered by overburden with a few embedded boulders. There is availability of space for the intake structure.

In general, the slopes of the right and left abutments are favourable. As the structure is to be designed for overburden, proper keying/ anchoring of the weir, approach channel and tail apron may be required. The site is also comfortably clear of the slide zone and predominance of large sized boulders in the upstream. The present diversion site is more favourable as compared to Alternative I in regards to citing of the diversion structure.

5.2.2.1 Desilting Tank:

The desilting tank is proposed on the flat terraces of north east of Bala village, away from the fringe of the forested boundary. The structure may have to be designed for overburden and plenty of space for accommodating the structure is available.

5.2.2.2 Water Conductor System:

The WCS, passes through loose overburden (slope wash) with moderate vegetation cover. Embedded boulders have also been observed in the area. The WCS thereafter passes through gentle slopes. It cuts across nalas N1 and N2 where it may have to be provided with an aqueduct. The WCS may have to negotiate a ridge further downstream. This may have to be negotiated with sharp bends along the contour that may not be possible through pipes and hence open channel for the reach may have to be provided.

It is recommended that as the cohesive strength of the soil may not be high, a piped WCS instead of an open channel may be favourable. The pipe must be anchored properly to ensure that it remains on its intended alignment and remains free of slumping through geotextile wrap, concrete collar or screw anchor as possible alternatives. Anchoring rebar in a X pattern could be useful. However it is a matter of design and a decision to this effect may be taken at that end.

5.2.2.3 Forebay:

The forebay site is proposed along the slopes at a slightly lower elevation to the motorable road. Rock is exposed around the forebay location, and it may be available at the foundation grade. Sufficient space is available for accommodating the structure.

5.2.2.4 Penstock:

The geological conditions along penstock alignment after forebay location is same as in Alternative-I. At El ±1426m, a kink has been given to the alignment. A prominent kink to the otherwise straight penstock alignment may lead to some energy losses, which needs to be worked out. The kink can however be smoothened to minimize losses in head. However, it is expected that losses may not be substantial. Thereafter, it passes through the low lying terraces on the left bank and may have to be totally designed for overburden. As the alignment of the penstock passes through overburden, proper and deep anchoring of the penstock pipes may be required. The alignment crosses a gully where proper slope cushioning may have to be provided.

5.2.2.5 Powerhouse:

The powerhouse location in Alternative-II is proposed on a river terrace and thus may have to be designed for overburden. In view of the safety of the structure and gain in head, the powerhouse location in Alt. II appears to be feasible and a better proposition over the location in Alt: I.

5.3 Phulibagar- Kwiti HE Scheme:

The proposed diversion site is located immediately downstream of a foot suspension bridge across Jakula Nadi (Figure 6**).** A major landslide occurs on the left abutment of Jakula Nadi, approximately 300m u/s of the weir site location. There is development of a slide just upstream of the diversion site. However, it may not pose a problem for the diversion structure. The width of the river at site is 25m. Boulders are seen strewn over the river course. The gradient of the river at this site is moderate.

The rock has beds dipping 20-45° towards N10°-N50°E. Prominent sets of joints include (J1) N300°-N340°/ 68°-80°, (J2) N170°-220°/70°-78° and a random set. Insitu rock is exposed along the course of the river just upstream of the footbridge. Thin patch of insitu rock exists on both the abutments but the structure may have to be founded on overburden on a permeable foundation with a suitable cutoff. Barring sparse exposure of rock along the course of river just u/s of the foot bridge, the abutments in general are under overburden cover. Both the abutments at the diversion site have a low to moderate slope and appear stable. The rock line has receded deep inside on the left abutment and therefore a flattish terrace has been created. This has a positive implication on the weir site location because the left bank slopes along Jakula from Burthing to Tejam are in general prone to sliding but the present weir site may be free of any such geological problem. There is also availability of space for the intake structure.

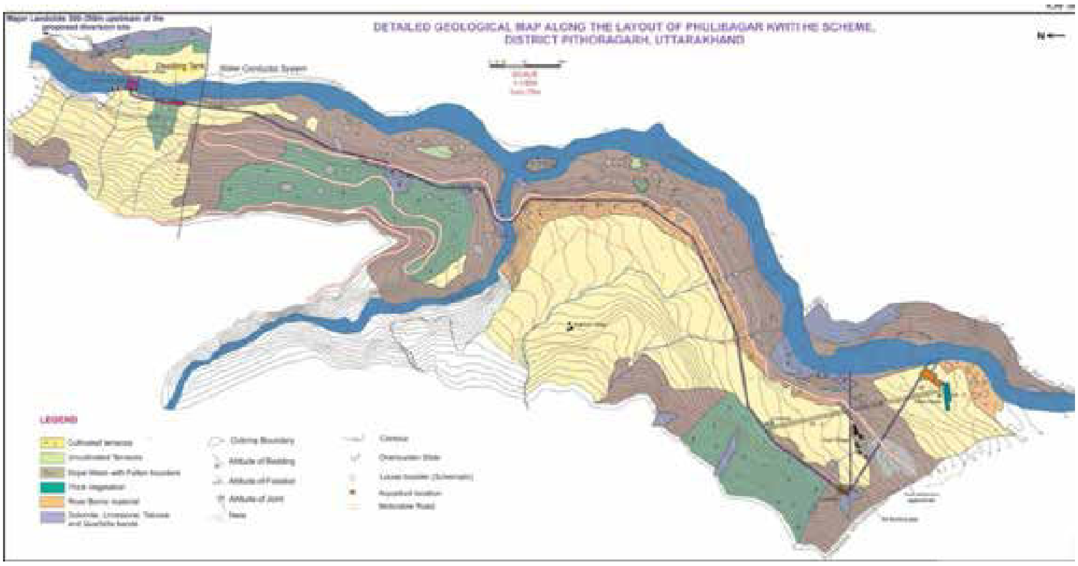


Figure 6 Detailed Geological Map along the layout of Phulibagar-Kwiti HE Scheme, District Pithoragarh, Uttarakhand.

5.3.1 Desilting tank:

The proposed desilting tank location lies over a mild depression, which is covered with scrubs and bushes. Boulders can also be seen in the reach. The vegetal growth could be due to the seepage of water from an adjoining gully. It is recommended that the proposed location be shifted slightly downstream on the flat terraces as the present site may not be feasible. In view of the major slide zone in the upstream portion, it is expected that the river may bring along higher silt proportions, which may adversely affect the free flowing WCS pipes. This aspect needs to be addressed appropriately. It may be advisable that the capacity of the desilting tank be enhanced to check the excess silt in the discharge although a decision in regards to the matter may be taken by the project authorities.

5.3.2 Water Conductor System:

The 1.218 km long WCS, passes through flat terraces after the desilting tank location. It meets the road level ~240 m north of the confluence of *Runliya Gad* and Jakula river. At the road intersection, insitu rock is exposed which may be useful in anchoring the WCS pipes. The WCS is expected to cross, a major right bank tributary, the Runliya *Gad*. There may not be much of a problem in negotiating this *gad*. The WCS may have to be provided with an aqueduct at this juncture. The width of the *gad* at this location is ~50-

55m. Rock is available on the left abutment of the gad and partially towards the base on the right abutment.

Immediately downstream of Runliya *gad*, on its right bank, an elevated terrace (~50-60m high) with a steep profile may interfere with the alignment of WCS. The terrace continues along the motorable road and the height of the slopes varies from 10m-60m.This is the critical reach for locating the WCS. It may not be advisable to disturb the slope by any kind of excavation. It may be possible to found the WCS pipes over pedestals. This may involve excavation of the terrace only in the form of pits at the base of the pedestal, which may not disturb the stability of the slope faces.

Beyond this critical reach of nearly 540 m from the Runliya *gad*, the WCS passes through terraced cultivated field with a very gentle slope. It may have to negotiate two cross drainages, which may have to be crossed with an aquaduct. It is recommended that as the cohesive strength of the soil may not be high, a piped WCS instead of an open channel may be favourable (~ 180m). However it is a matter of design and a decision to this effect may be taken at that end.

5.3.3 Forebay:

The proposed forebay location is recommended to be shifted slightly upstream as the penstock alignment through which this location passes have dense settlements of Kwiti village and hence may not be feasible. The recommended forebay site lies along the flat terraces of village Majkot and Kwiti. Sufficient space is available for accommodating the structure. The slopes are gentle and appear stable. The alignment of penstock from this location doesn't interfere with any of the settlements.

5.3.4 Penstock:

The penstock partially is aligned along the gently sloping terraces of village Kwiti. It cuts across the motorable road, upstream of Kwiti village. Thereafter it is aligned along the overburden dominated slopes. At a lower level below the road head, about 65-70m of the penstock pipe may have to negotiate a slope inclined at 50-55°. Proper anchoring of the anchor blocks would be required in this zone. The remaining portion of the penstock passes through gentler slopes of a low-lying terrace of Jakula Nadi (Figure 7). The initial reach of the penstock can be guided over a frame and similarly the reach before the power house location where the ground profile is gently sloping. The intermittent reach of 65-70m between El 1260m and El 1210m could pose problems as rock may not be available at shallow depth. The penstock within this reach may have to embedded through deep anchor blocks fastened through saddle support through thick rod clamps with provision of expansion joints. Provision of proper slope draining arrangement would also be required as per design requirements.

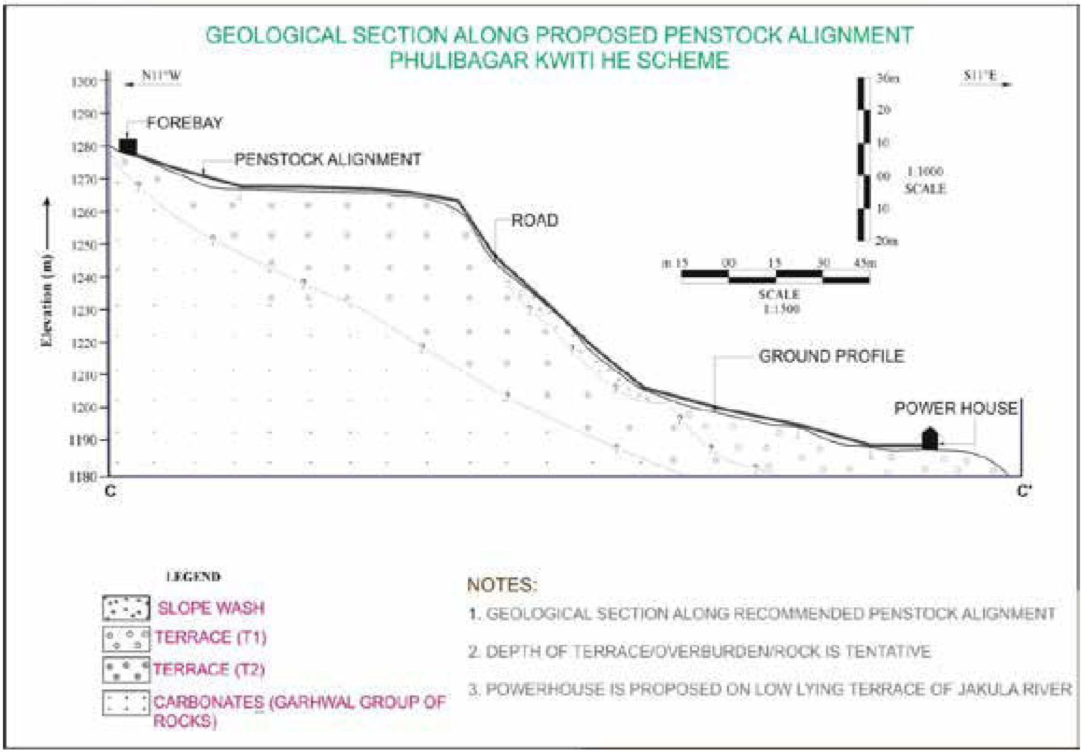


Figure 7 Geological section along proposed penstock alignment of Phulibagar HE Scheme, District Pithoragarh, Uttarakhand.

5.3.5 Powerhouse:

The powerhouse site is proposed on a low-lying terrace on the right bank of River Jakula. The structure may have to be designed completely for overburden as the area is devoid of any outcrops. The site appears feasible.

6. Merits of the Schemes:

1. The discharge (0.96 cumec) of Birthi Fall HE Scheme which as per earlier proposal was going unutilized can now be productively utilized contributing to the power potential of Burthing Purdam HE Scheme.
2. No specific diversion structure or water conductor system may be required except for penstock component making Birthi Fall HE Scheme, a very cost effective scheme.
3. The Birthi Fall being a known tourist spot can be further developed from tourism point of view considering that it has tremendous tourism value attached to it.
4. The penstock slopes are rocky and therefore may not be a problem anchoring the penstock.
5. The powerhouse for the Birthi Fall scheme may be considered as a captive powerhouse scheme.
6. Extremely favorable water conductor slopes for the Burthing Purdam scheme all along its length is an attractive proposition.

7. Gaining about 200m of head over a length of ~2.0 km for the scheme is appreciable.
8. The discharge of Birthi Fall Scheme would add to the power generation of this scheme in the downstream.
9. The Phulibagar Kwiti HE scheme would in turn utilize the tail waters of Birthi fall and Burthing Purdam HE Scheme in addition to the catchment area of $68km^2$.
10. The site for the scheme is suitable from topographical, hydrological and geological view. The major appurtenant structures would have to be designed for overburden with no tunneling, damming or major land acquisition and most importantly no interference with the environment.
11. The three tail to tail schemes may be taken up and developed in conjunction thus cumulatively producing ~15MW of hydro power.

7. Conclusions:

The schemes identified can primarily support Run of the River (ROR) schemes in preference to storage schemes. Emphasis has been laid on smaller diversion structures and its variants like trench weir. Wherever the slopes have been found favourable for water conductor system, surface WCS have been preferred over pressure tunnels to minimize costs. Unavailibility of rock as foundation has encouraged designing structures for overburden. The three investigated schemes in the rugged Himalayan terrain discussed above are apt examples of how, smaller, more affordable schemes can be conceived with judicious planning, low costs and minimal interference with the environment. Water is precious. Not an inch of land or drop of water is to be wasted. Such smaller schemes would go a long way in providing substitute for bigger projects lying in dormancy for years together. This would productively contribute to the economy of the nation.

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