CLIMATE-RESILIENT DAMS AND

HYDROPOWER INFRASTRUCTURE

INTEGRATING

ENVIRONMENTAL SUSTAINABILITY

IN PLANNING AND DEVELOPMENT

Application of tracer techniques for detecting dam leakage

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THREATS FOR SUSTAINABILITY OF A DAM*

- Sedimentation
- Leakage

LEAKAGE, a condition that can prove both hazardous & costly, is undesirable at most reservoirs

- However, some water loss often occurs, and is tolerated when it imposes no threat to safety and its' preventive measures are either technically not feasible or too costly

- Leakage Avoidance and Prevention

  - A common mistake made at many past projects: Concentrate investigation on the dam site while paying only cursory attention to the reservoir area#

  - Many dams located in exceptionally favorable topographical settings have leaked excessively when filled*

* REFERENCE: Case Studies of Dam Failures. In: Engineering for embankment Dams (Bharat Singh & R.S. Varshney)

INCIDENTS OF DAM FAILURES IN INDIA

LEAKAGE AND/OR WRONG SITE SELECTION*

1) Panshet Dam, Maharashtra [in July, 1961]
   Wrong site selection, ultimately resulted in heavy leakage
2) Nanak Sagar Dam, Uttar Pradesh [in August, 1967]
   Wrong site selection & design, ultimately resulted in heavy leakage
3) Sampna Dam, Madhya Pradesh [in June, 1964]
   Wrong design, ultimately resulted u/s slip of the dam
4) Machchu Dam II, Gujarat [in August, 1979]
   Wrong site selection & design, ultimately resulted in overtopping of the dam
5) Karam Dam Breach (August 2022):
6) Jagersfontein Tailings Dam Failure (September 2022):
7) Derna Dam Collapses (September 2023)

VARIOUS TECHNIQUES FOR DAM SEEPAGE/LEAKAGE INVESTIGATIONS

1) **Non-Tracer Techniques**
   - Water balance of the reservoir
   - Relationship between reservoir water level and seepage rates
   - Water injection tests in boreholes
   - Geophysical methods
   - Piezometric studies
   - Vertical flow measurement in bore holes using current meters

VARIOUS TECHNIQUES FOR DAM SEEPAGE/LEAKAGE INVESTIGATIONS

2) **Tracer Techniques**

- **Using Natural Tracers of water**
  - In-situ physico-chemical parameters (EC, T, pH, DO etc)
  - Environmental Stable isotopes (^{18}O & ^{2}H)
  - Environmental Tritium (^{3}H)
  - Environmental Carbon-14 (^{14}C)

- **Using Artificial Tracers (Radioactive and/or Non-Radioactive)**
  - ^{131}I, ^{82}Br, ^{198}Au, HTO, Chemical & Dye Tracers etc

Combined use of Non-Tracer and Tracer Techniques has proven to be best suited for investigating many dam/reservoir leakage/seepage problems

ENVIRONMENTAL ISOTOPE METHODS FOR DAM SEEPAGE INVESTIGATIONS

Environmental Stable Isotopes [^{18}O & ^{2}H]

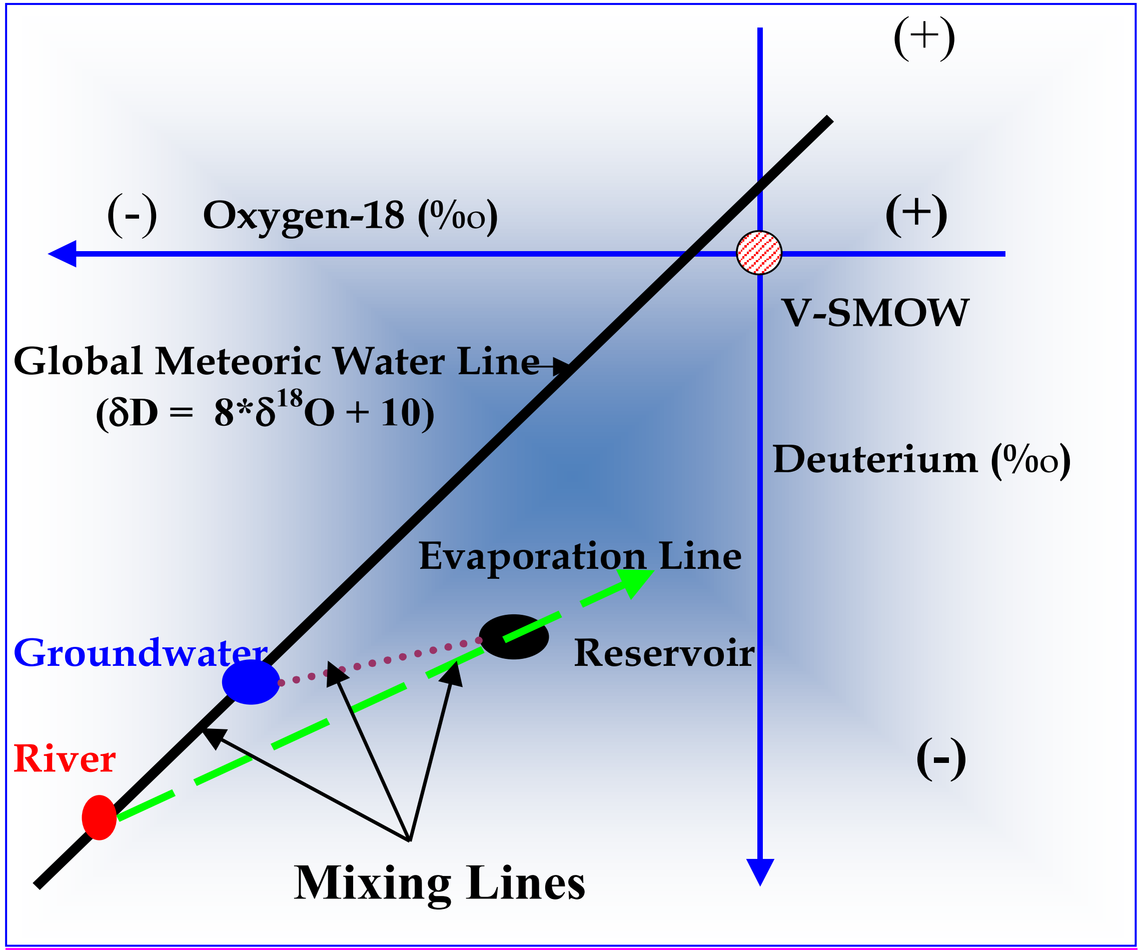
- Origin of the water emerging d/s of a dam?
  - Exclusively local GW
  - Real leak connected to reservoir
  - Mixture of both components

^{18}O & ^{2}H of natural waters depend on:

- Origin (latitude, altitude etc)
- History (condensation, evaporation, mixing with other waters etc)

Thus, by comparing ^{18}O & ^{2}H of seepage water and its suspected sources:

Possible to confirm or rule out the possibility of interconnection



Theoretical δD-$\delta^{18}O$ relationship of different types of water interacting in the vicinity of a reservoir

Environmental Isotope Methods for Dam Seepage Investigations ……..continued

In some cases,

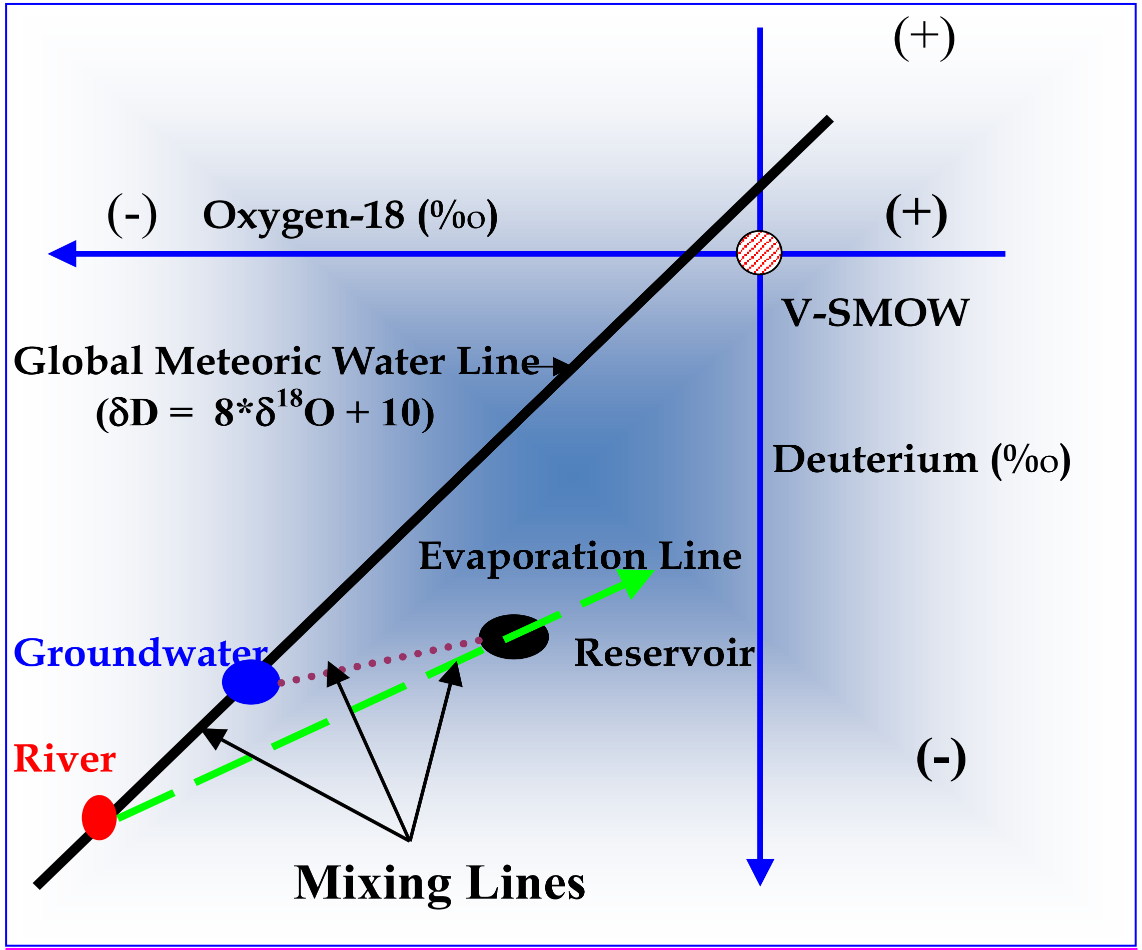
- ^{18}O & $^{2}H]_{Reservoir}$ = ^{18}O & $^{2}H]_{Groundwater}$ = ^{18}O& $^{2}H]_{River}$

  - ➢Environmental stable isotopes cannot be used as a natural tracer

- In those cases, environmental tritium (^{3}H) may be used, if measurable differences exist, to obtain similar information like stable isotopes:

  - ➢ Possible to confirm or rule out the possibility of interconnection

  - ➢ Dating of different waters associated with a dam problem



Theoretical δD-δ18O relationship of different types of water interacting in the vicinity of a reservoir

RADIOACTIVE TRACER METHODS FOR DAM SEEPAGE INVESTIGATIONS

1) FLOW TESTS IN BOREHOLES

- Identification & measurement of flow patterns in boreholes using artificial tracers is an essential tool to know the seepage paths

1.1) Point Dilution Technique

Measurement of horizontal groundwater velocity

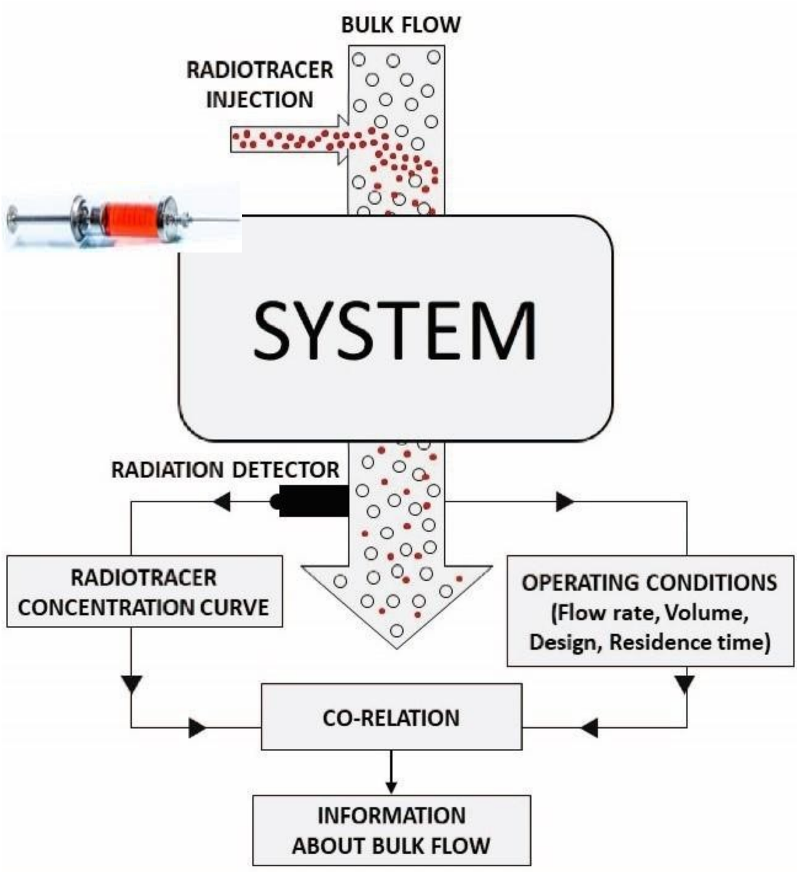
1.2) Point Injection Technique

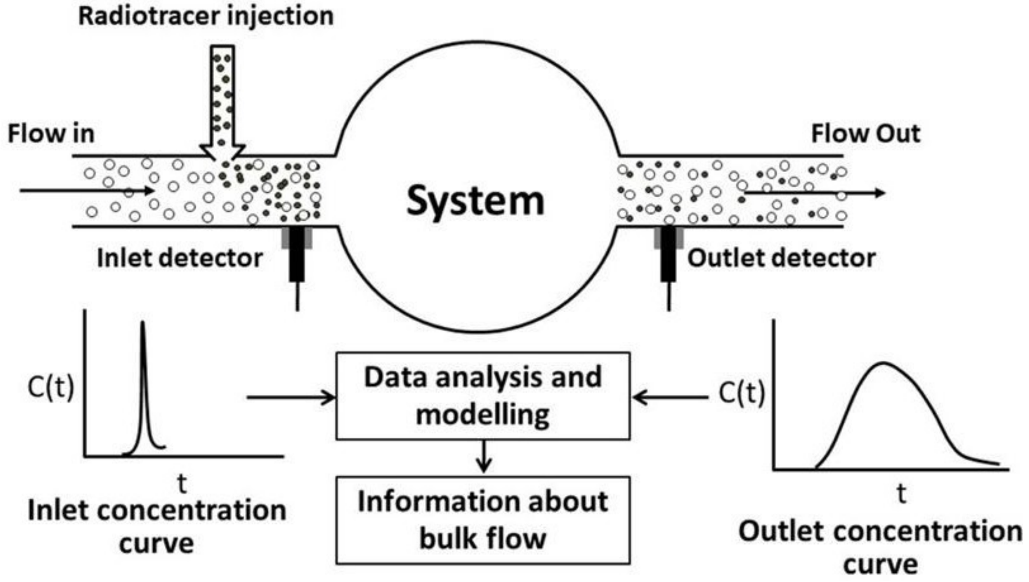
Measurement of vertical groundwater velocity

1.3) Labelling of the whole Water Column Technique

Qualitative and semi-quantitative information of groundwater velocity (both, vertical and horizontal)

RADIOACTIVE TRACER METHODS FOR DAM SEEPAGE INVESTIGATIONS



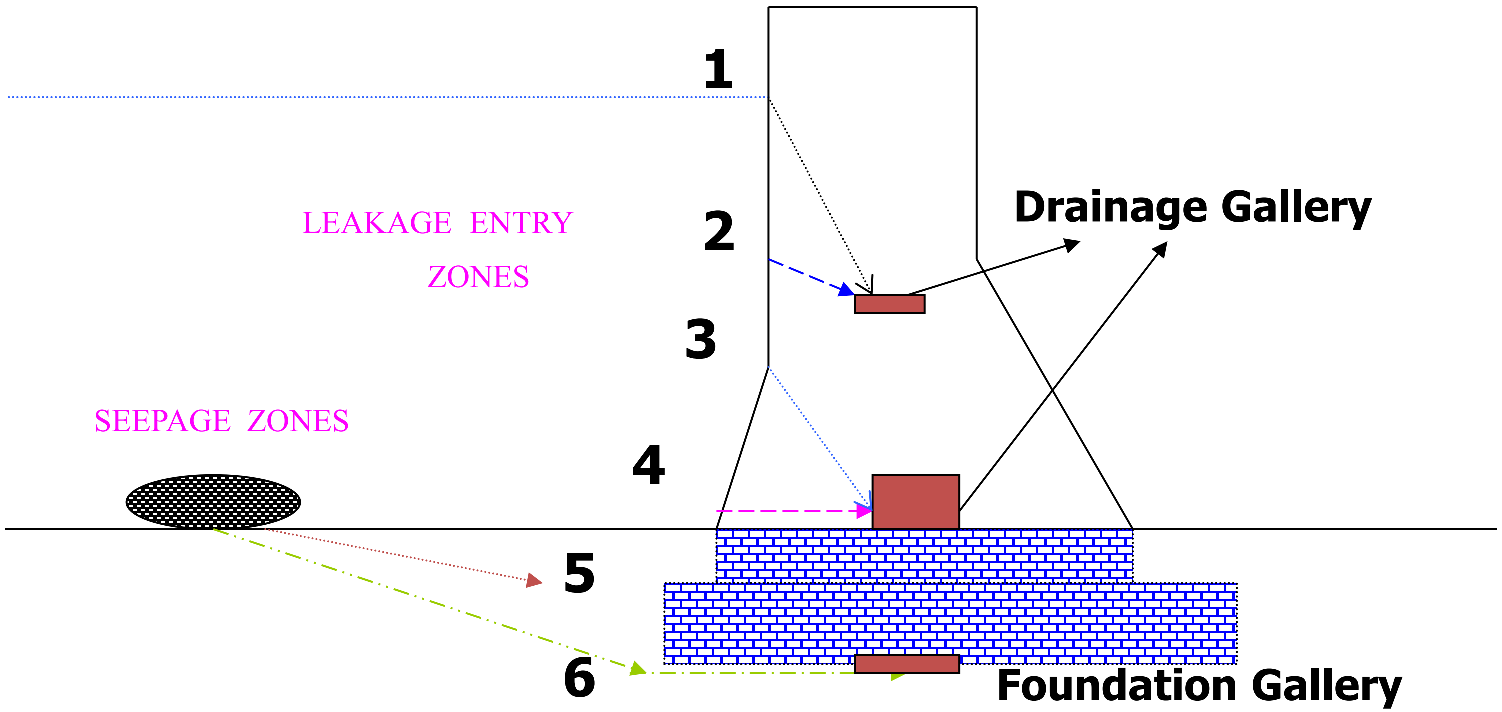


RADIOACTIVE TRACER METHODS FOR DAM SEEPAGE INVESTIGATIONS

- **IF THE SEEPAGE/LEAKAGE HAS NOT OCCURRED,**
  Periodic investigation on the Pathways of the groundwater around the vicinity of the reservoir

  - **For assessing the risks derived from the local groundwater flow to dam and/or**

  - **For determining the possibility of constructing a grout curtain or other type of impermeable barrier in order to stop or to reduce the subsurface flow**



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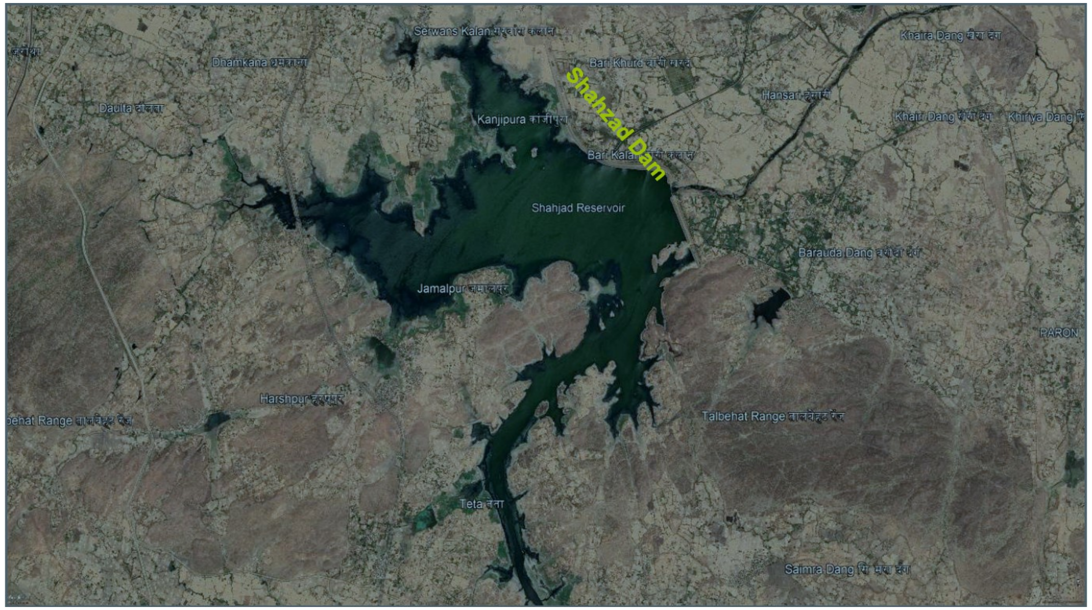
CASE STUDY 1: Shahzad Dam, UP



•**Location:** Talbehat, Lalitpur district, Uttar Pradesh.

•**River:** Shahzad River. (Year 1992)

•**Capacity:**

- Designed gross capacity: 127.420 MCM.
- Live capacity: 118.930 MCM.

Dimensions:

Height 18 m; Length 4160 m

321.00 m Max WL; 310.0 m Min WL;

116.60 km canal system; 14403 ha land for irrigation

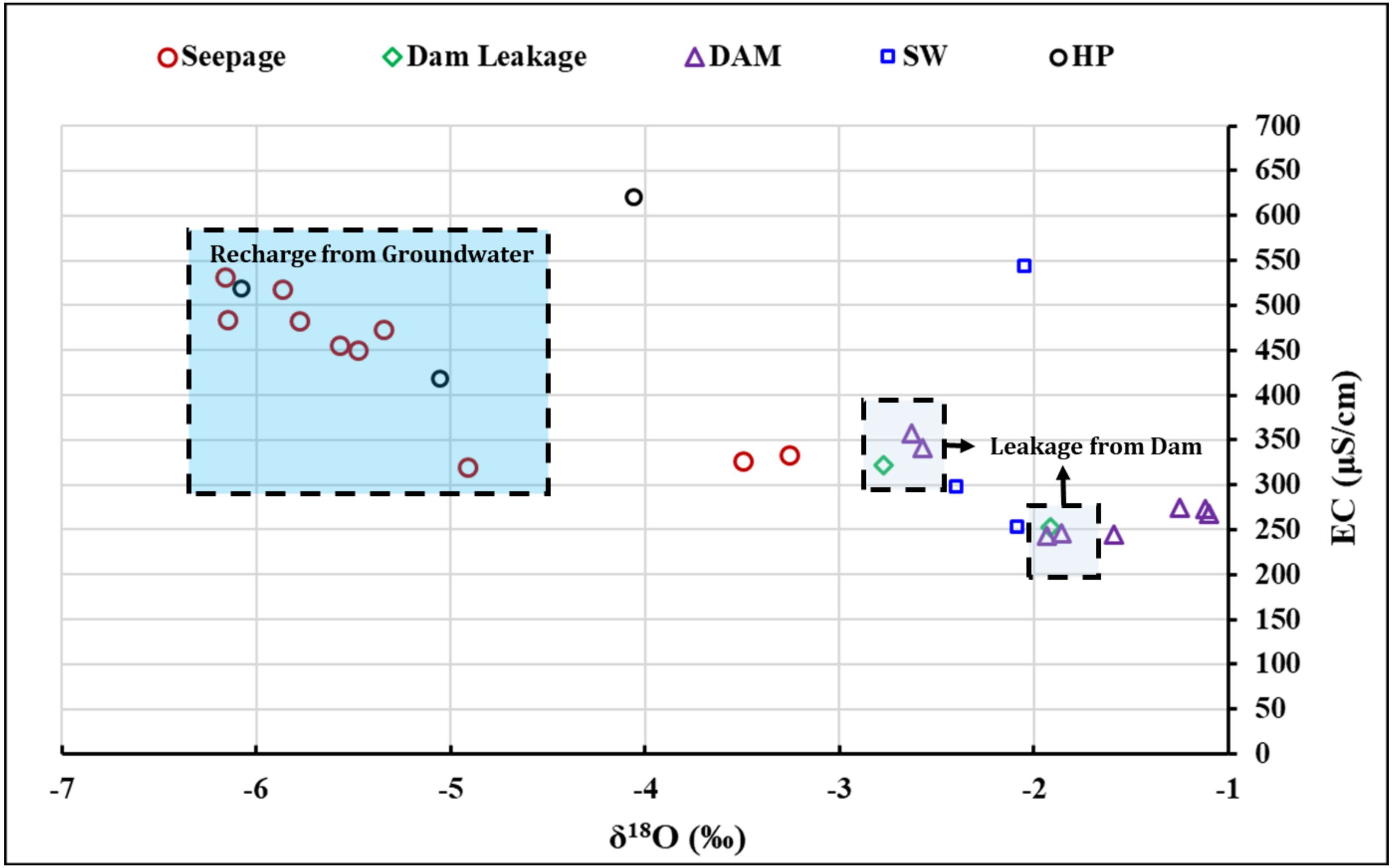
•**Morphometric Analysis:** high permeability, high infiltration capacity, and low surface runoff.

•**Geological Formation:** Lalitpur district is characterized by crystalline rocks (granite, gneisses, schists, quartz reefs, mafic rocks) and sedimentary rocks (sandstone, shales, carbonate rocks).

Field Photograph

Climate-Resilient Dams and Hydropower Infrastructure: Integrating Environmental Sustainability in Planning and Development

SOURCE IDENTIFICATION
Confirmation with EC



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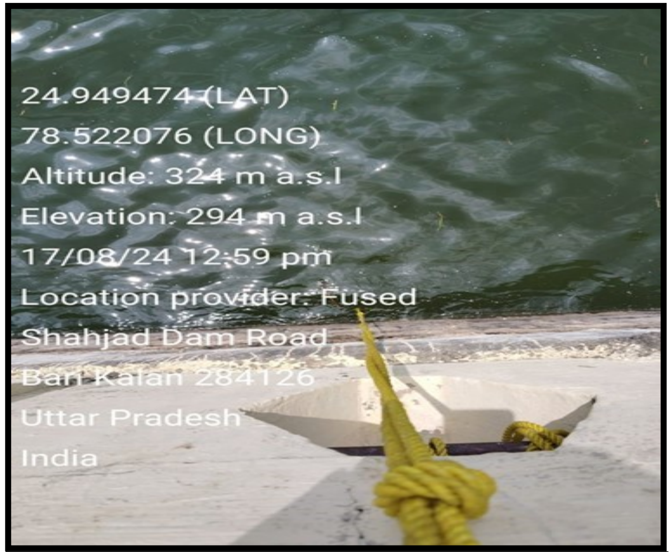
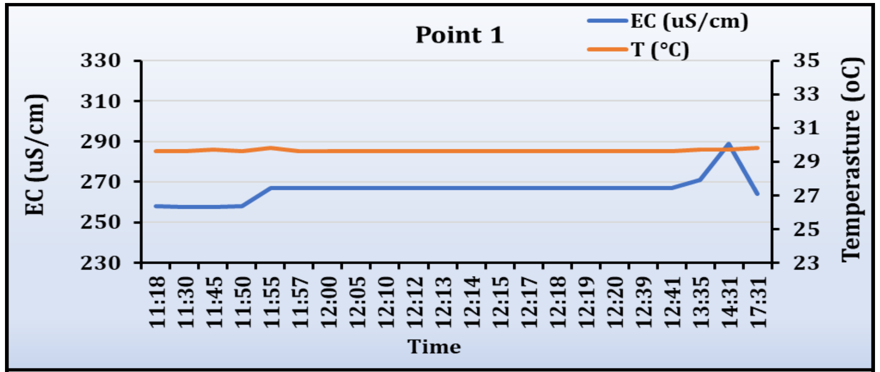
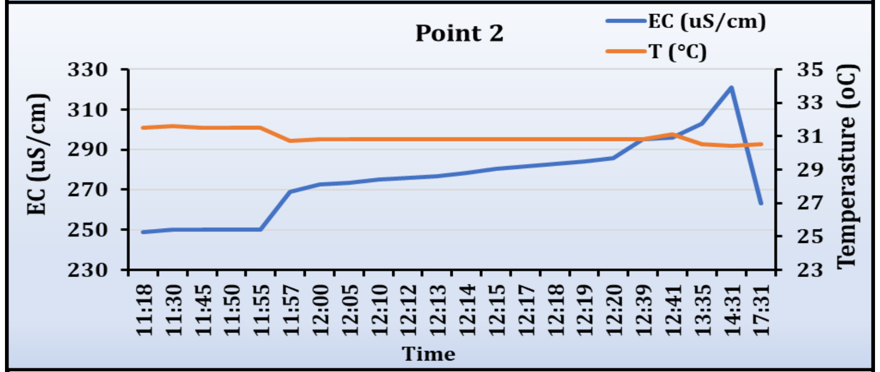
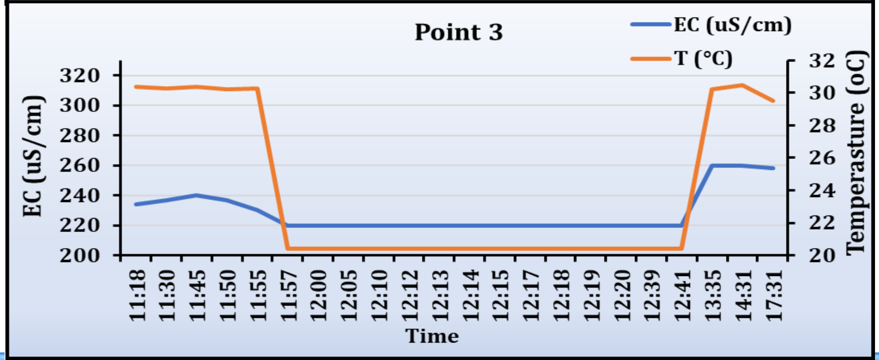
SITE IDENTIFICATION









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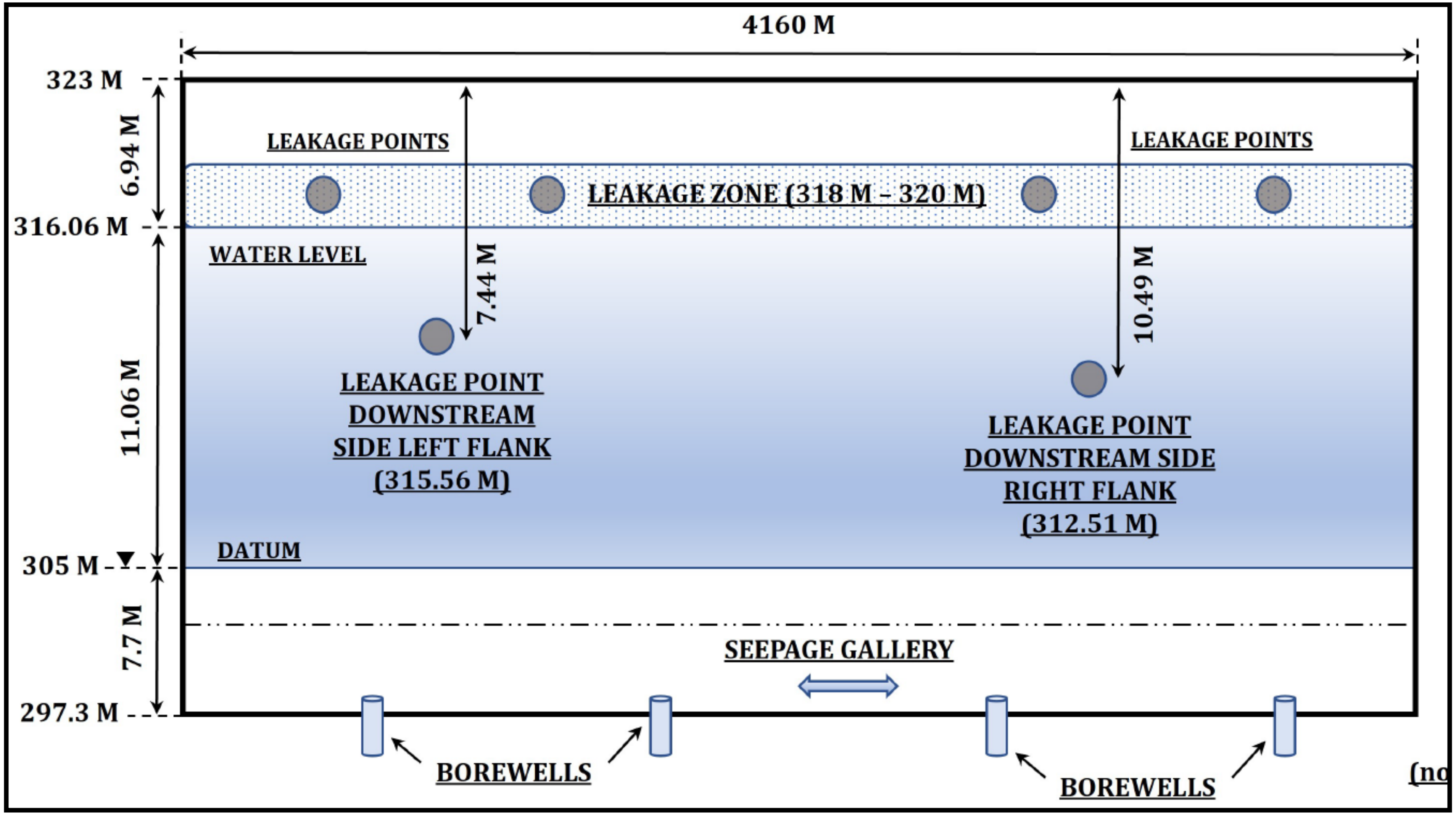
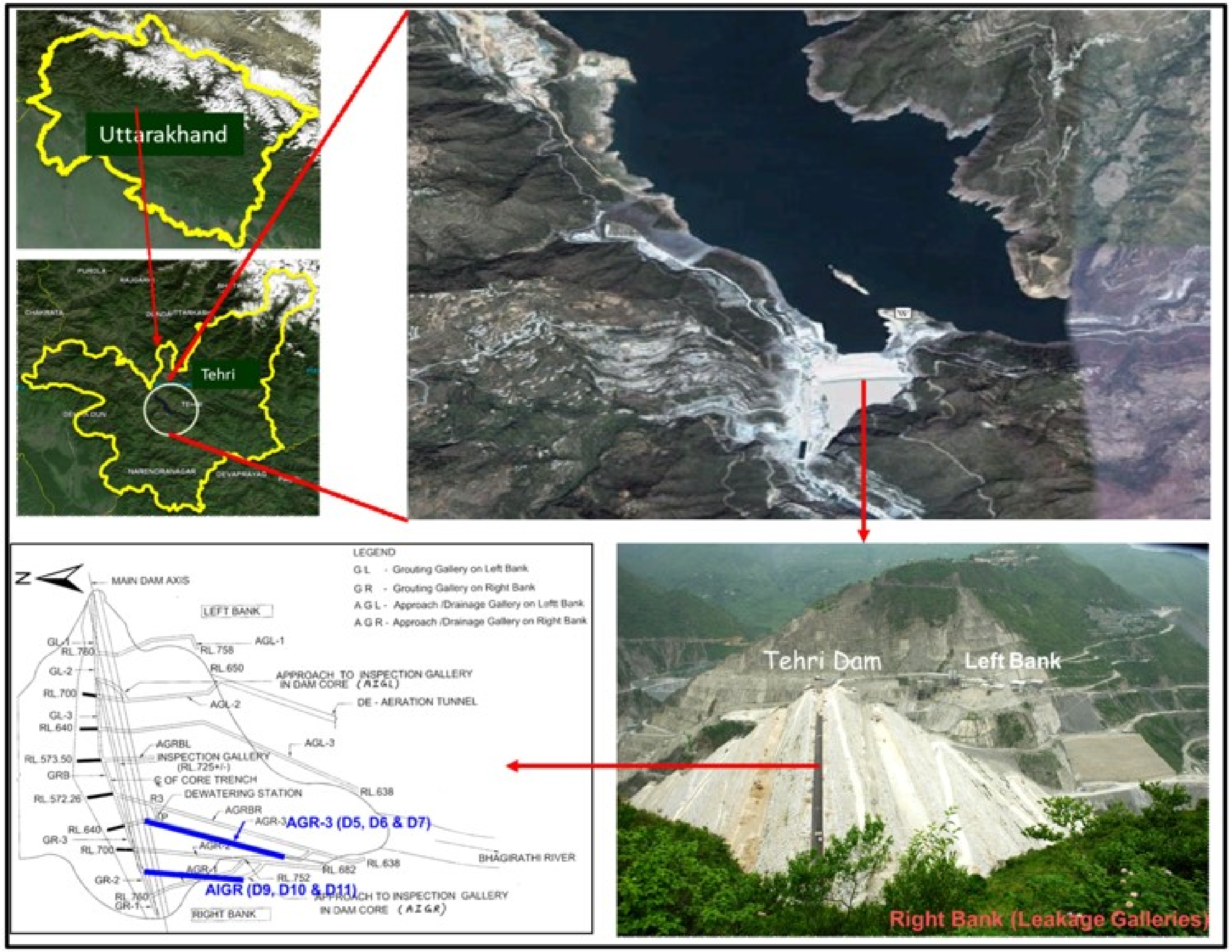
CONCEPTUAL MODEL

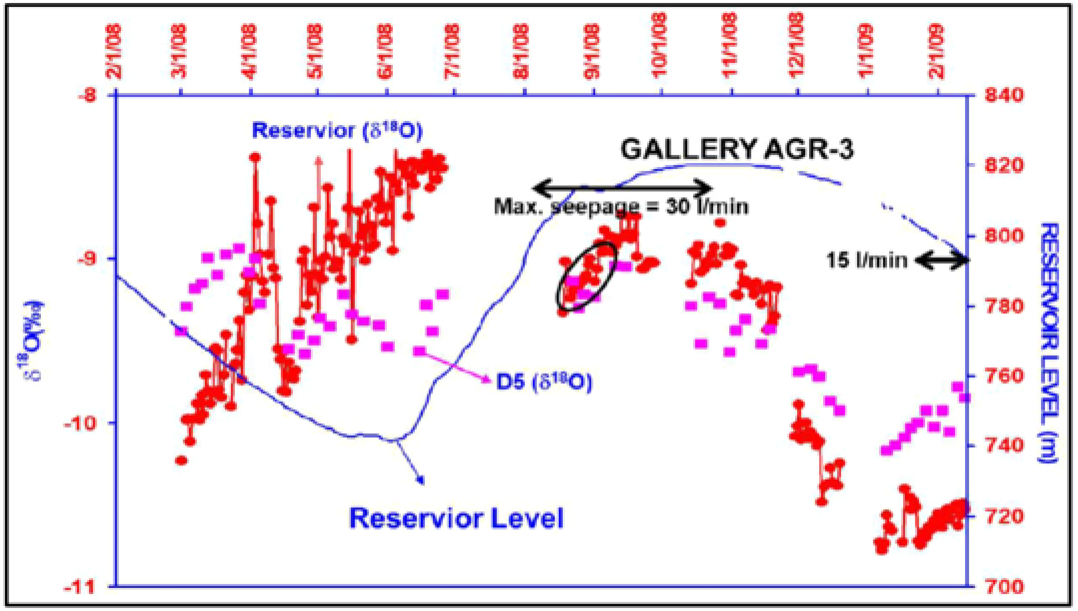


CASE STUDY 2: Tehri Dam, Uttarakhand

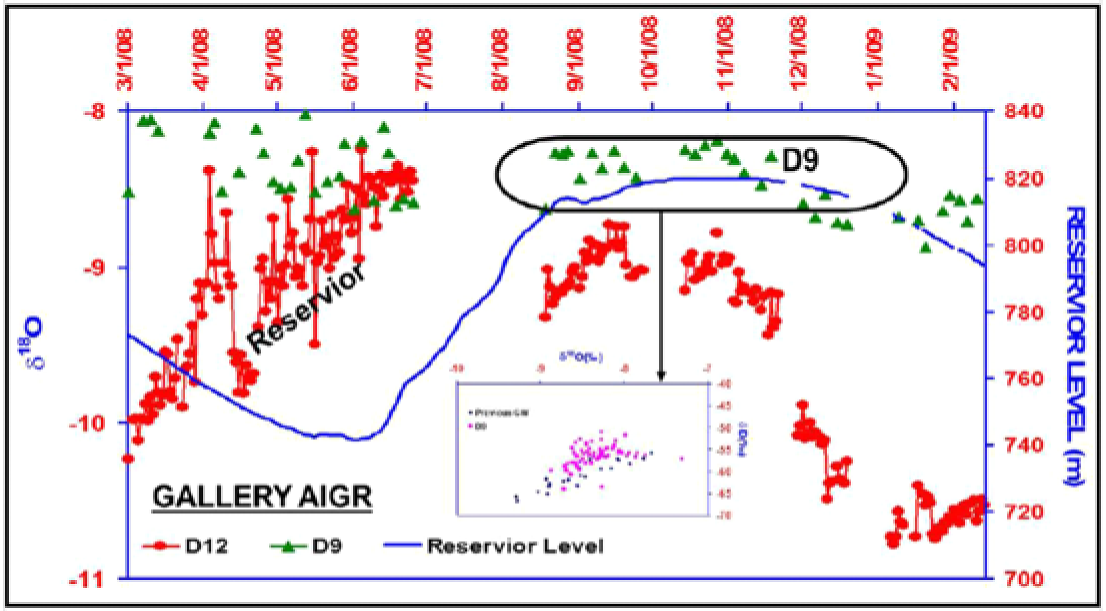


- **Location:** Tehri, Uttarakhand.
- **River:** Ganga

Isotope investigation

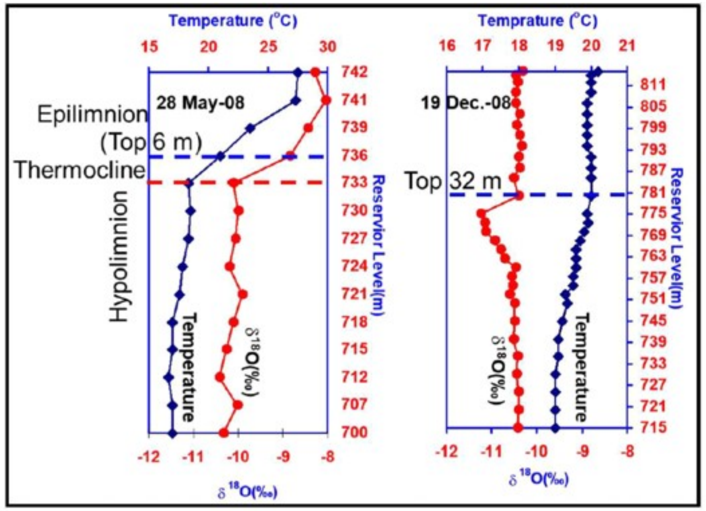


Results clearly indicates that seepage from site D5 is connected with Reservoir



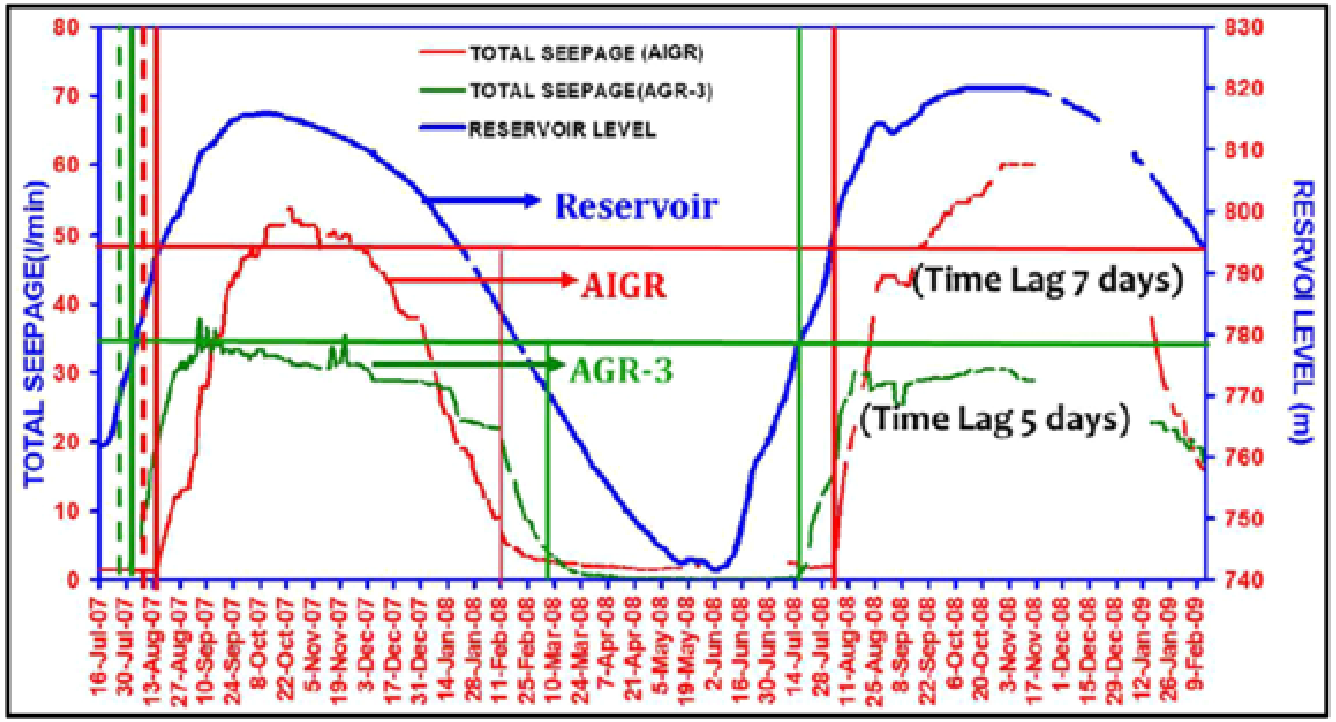
Results clearly indicates that seepage from site D9 is rain fed, not connected with Reservoir

Recharge Area



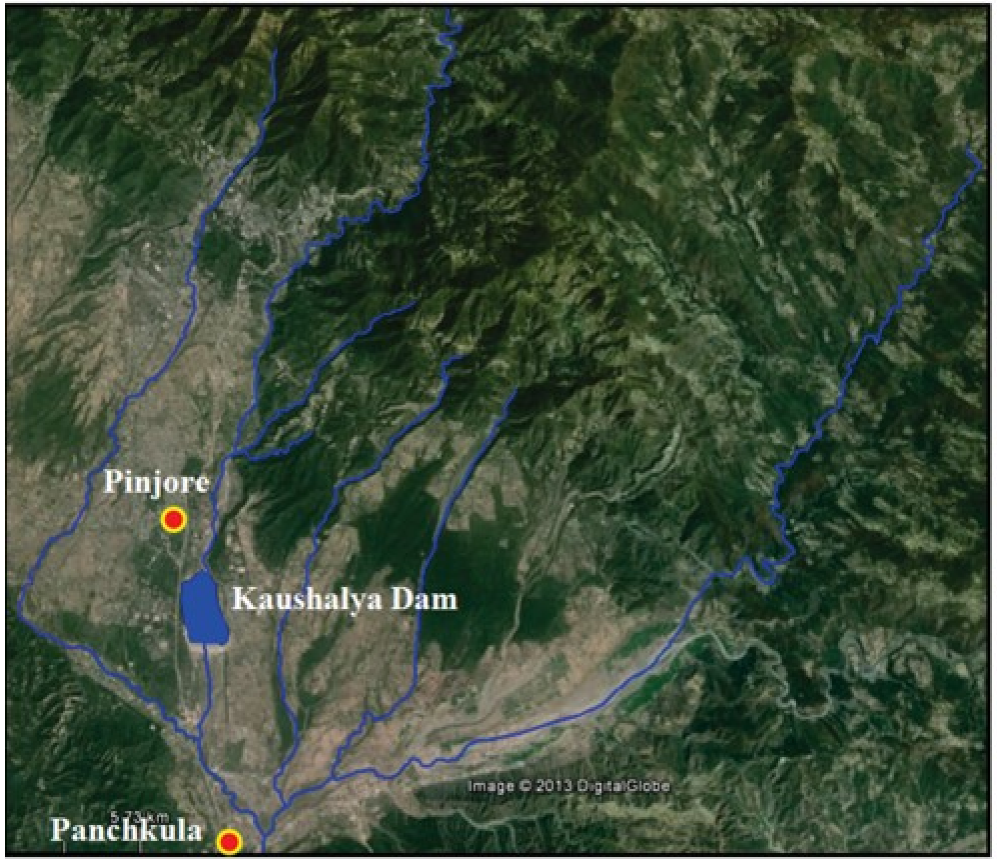
Isotopic Composition ranges between -8‰ and -10.3 ‰ in the month of May and -10.3 ‰ and -11 ‰ in the month of December. It clearly shows that reservoir is under stratification during summer months and during winter (December, January and Feb) it under goes in mixing stage

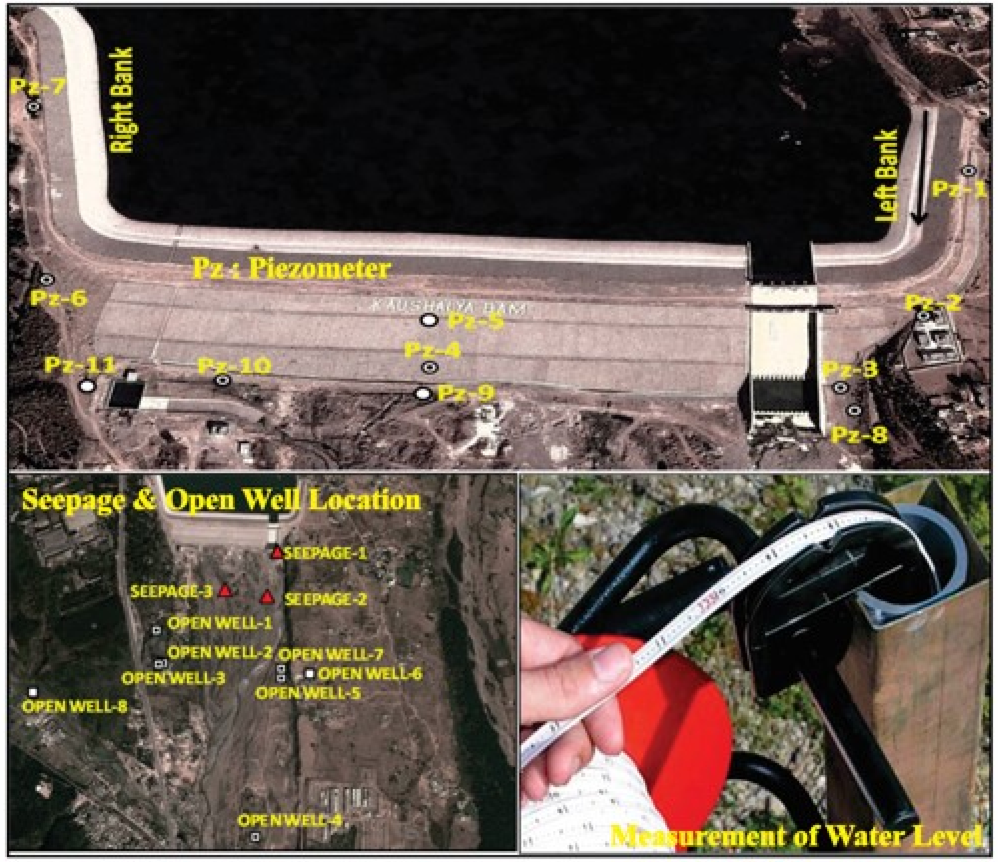
- Discharge and isotopic composition indicates that seepage in both the galleries are from the two separate fracture zones.
- 1st zone is located approximately between the elevation range of 771 and 800 m (D5, D6 and D7 of AGR 3 Gallery)
- 2nd Zone is located between 783 and 815 m (D9 & D10 of AIGR Gallery)
- Time lag is about 5 days in AGR-3 and 7 days in AIGR gallery.
- Seepage is mixture of reservoir leakage and recharge through the rain. However, the leakage water is major component in seeapge from galleries.



- In AGR-3 Gallery, seepage increases sharply at RL of 771 m in 2007 & at 773 m in 2008 it clearly indicates that leakage starts above the RL of 770 m.
- In AIGR Gallery, seepage increases sharply at RL of 783 m in 2007 & at 785 m in 2008 it clearly indicates that leakage starts above

CASE STUDY 3: Kaushalaya Dam, Haryana





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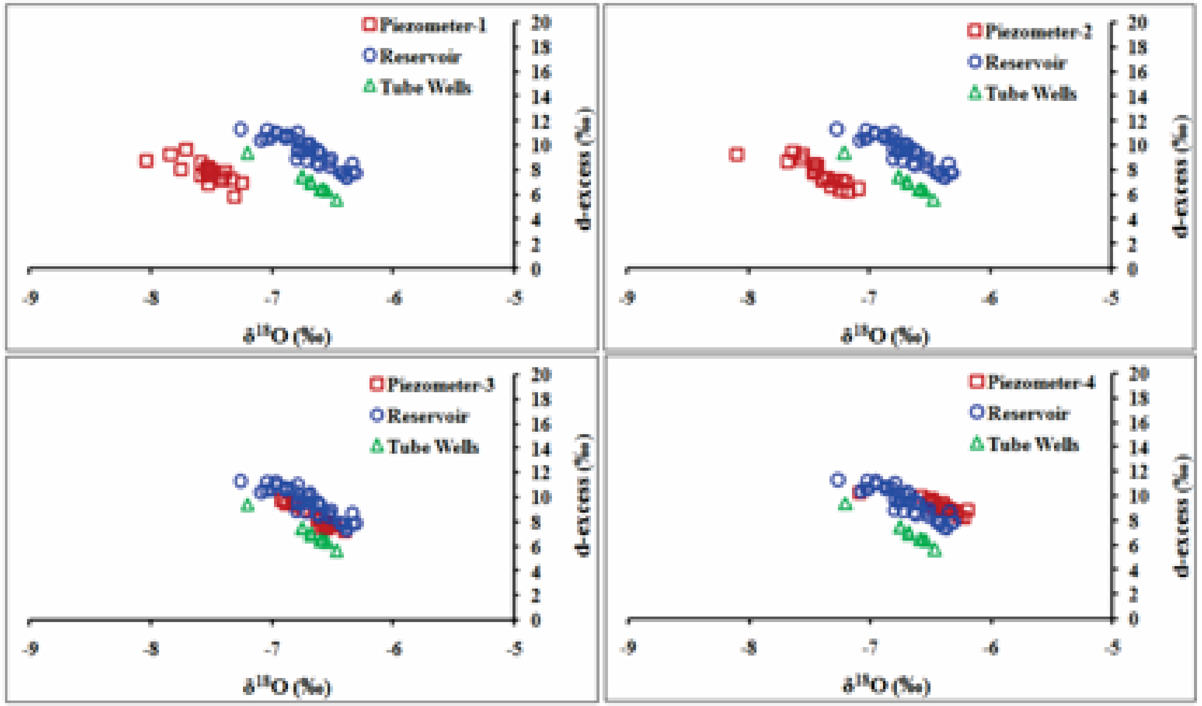
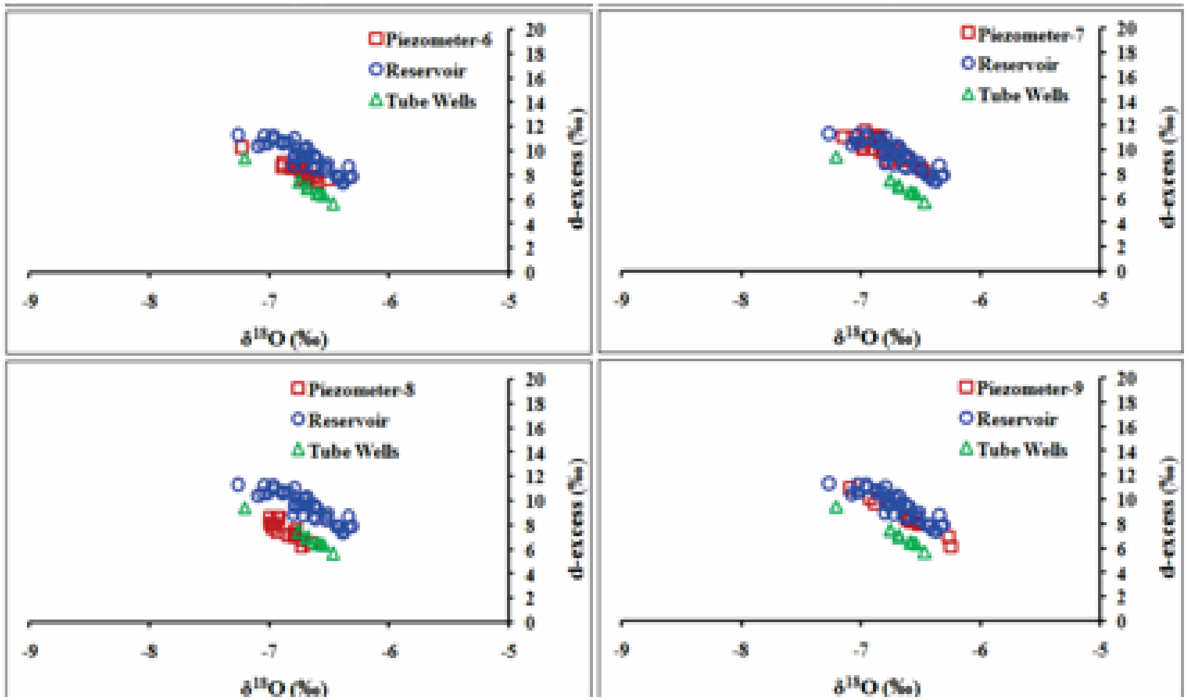
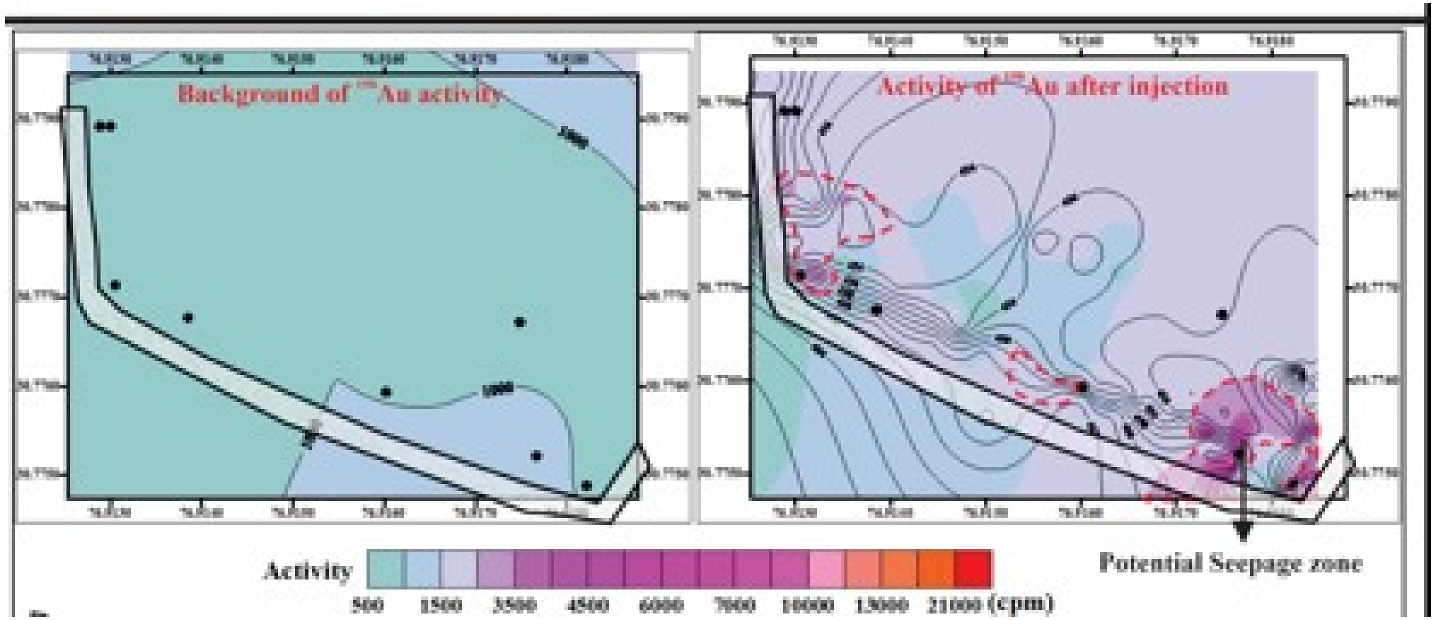
Isotope investigation





Tracer injection/source identification



Conclusions

- The investigation on leakage from and reservoirs **absolutely necessary before undertaking any repair work.**

- It requires the combined use of different techniques:
  Geological & hydrogeological reconnaissance starting point

- In addition, **use of artificial & natural tracers are important Some non-tracer techniques can provide very useful information** (water balance, response of leakage to reservoir level variations, piezometric observations etc)

MANY FAILURES OF DAM/RESERVOIR REPAIR WORKS EXECUTED WITHOUT APPROPRIATE PRIOR INVESTIGATION ARE KNOWN (INVESTIGATION COSTS ARE USUALLY NEGLIGIBLE IN COMPARISON TO REPAIR WORKS)


Thank You