# Uncertainty Estimation in Discharge Forecasting


HBV Team - 02/02/2024

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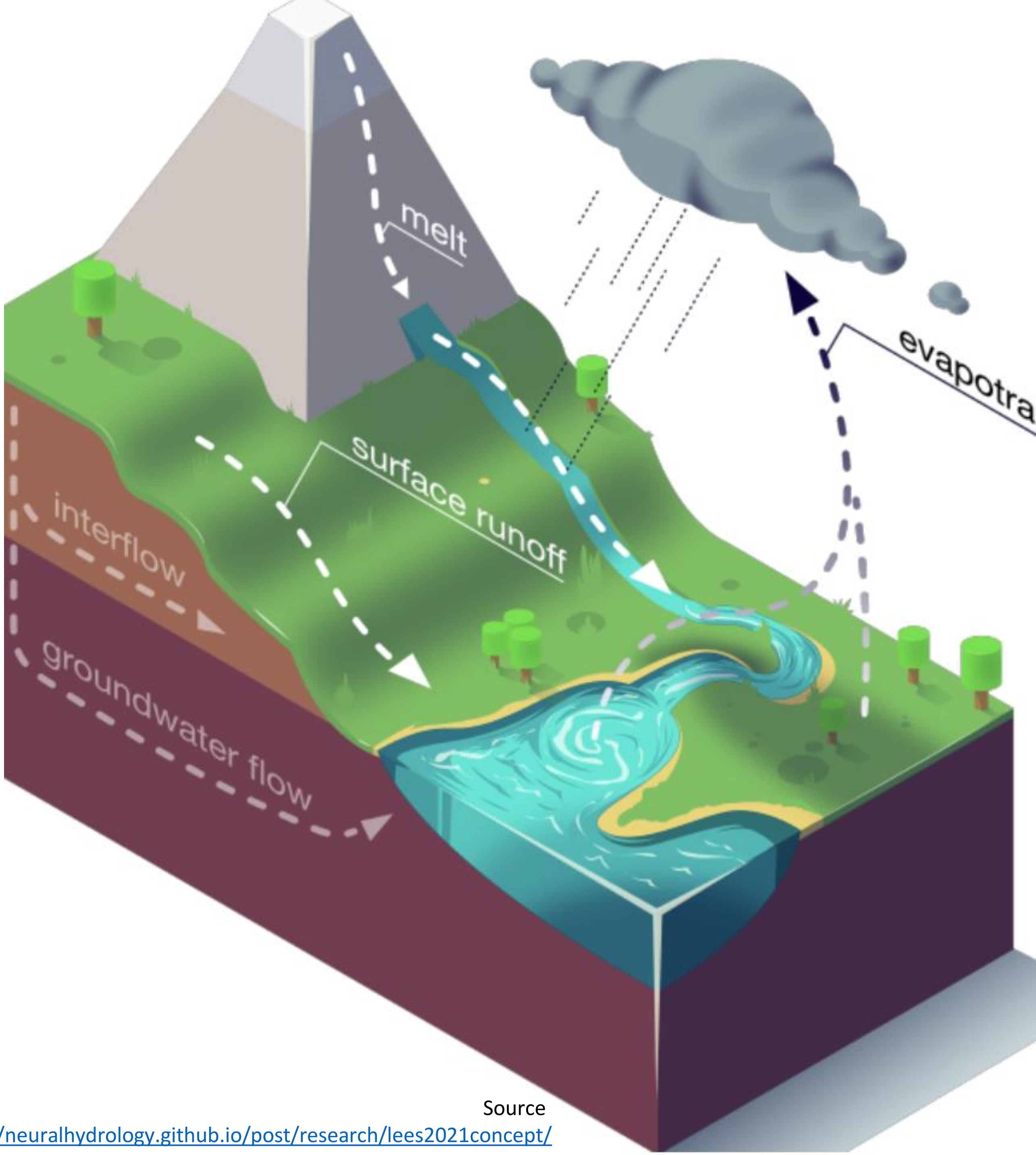
# Rainfall – Runoff

- **Rainfall-runoff:**
  - process by which precipitation interacts with the Earth's surface, leading to **runoff** / discharge.
- Influencing factors:
  - **Water flows**: Precipitation, infiltration, evaporation, snowmelt
  - Land use
  - Soil type
  - Topography
  - Etc.

**Rainfall-runoff is a crucial component of the hydrological cycle.**



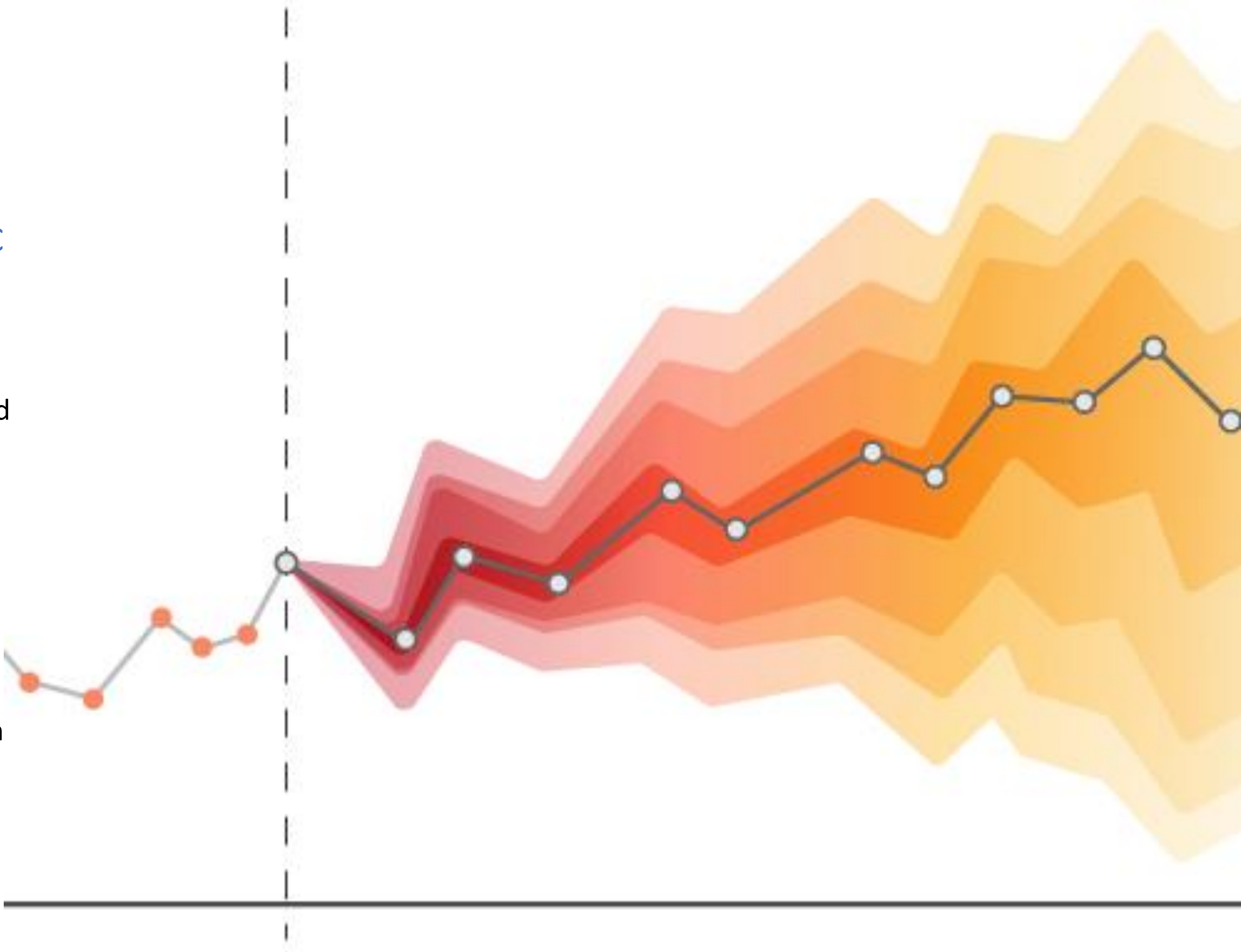

Source
https://neuralhydrology.github.io/post/research/lees2021concept/

# Significance of Modeling Rainfall-Runoff

- Risk mitigation and public safety
- Infrastructure protection
- Optimal water resource management
- Especially now in times of climate change, leading to more floods/droughts

# Need for probabilistic predictions

- At present, models are only used for deterministic results
- Probabilistic models provide uncertainty quantification, important for:
    - Risk assessment
    - Decision making
    - Water allocation
    - Climate Change adaptation



# Problem statement:

# Bridge the gap in uncertainty estimations in hydrological predictions

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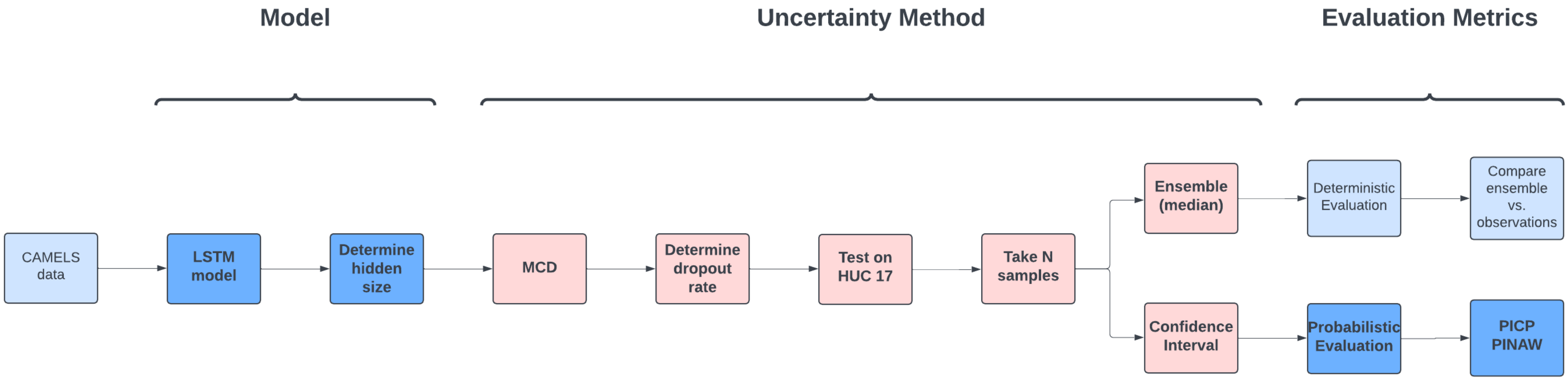
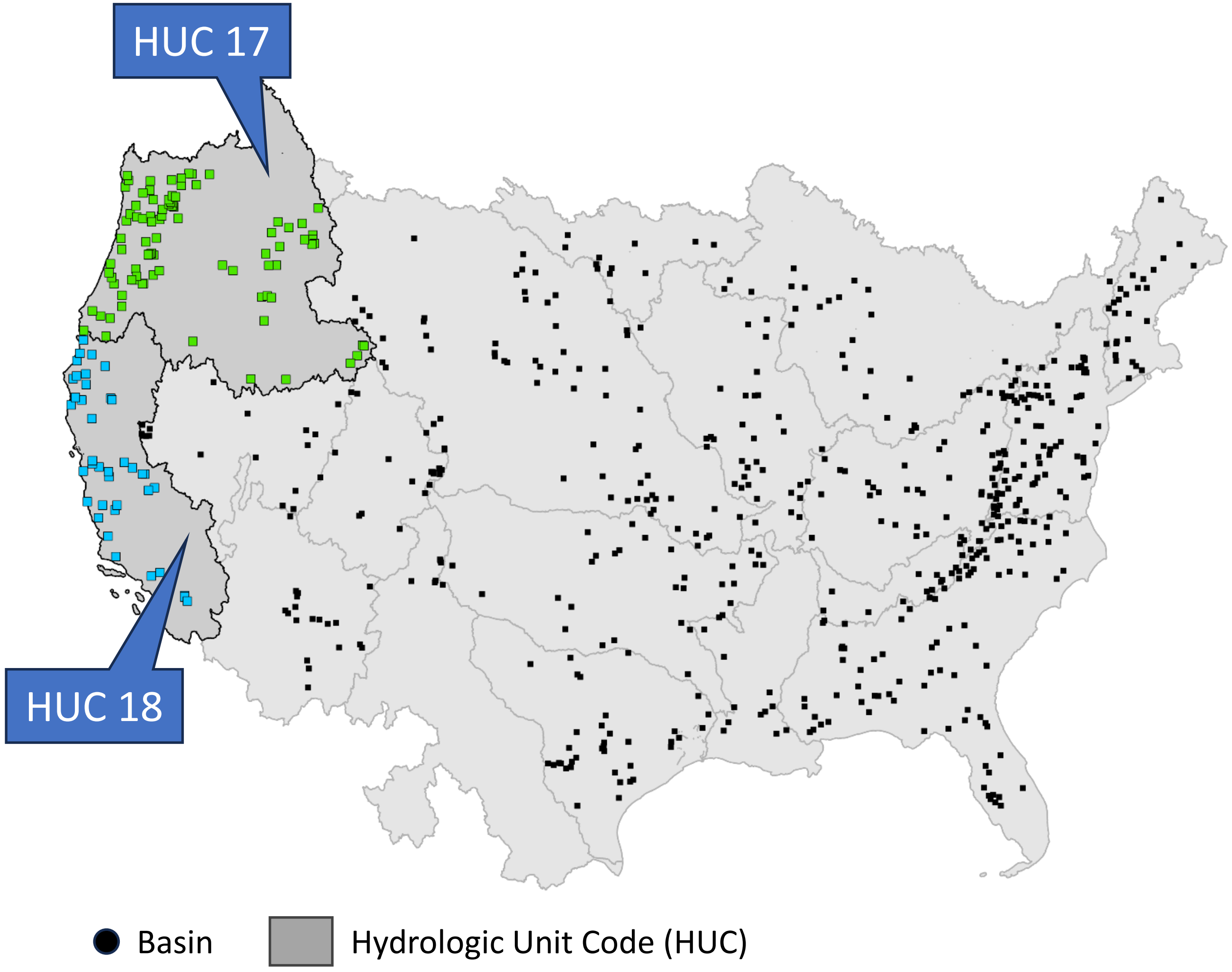



# Objectives/Workplan

**Main objectives:**

- Uncertainty estimation for discharge
- Exploration for evaluation metrics
- Investigation on transferability of model




# Data

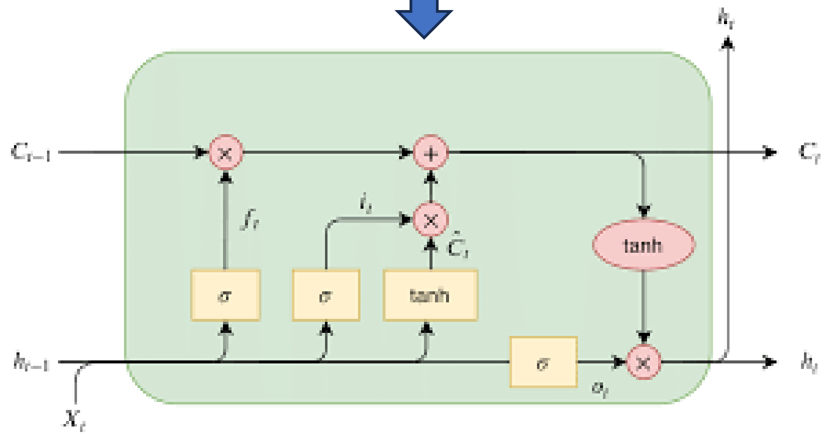
- Contains data for **671 USA basins**:
  - Meteorological time-series data
  - Streamflow data
  - Basin attributes
- For this project we selected **HUC 17** for our model and used **HUC 18** for Transfer Learning

# Long Short-Term Memory (LSTM) Model

- LSTM networks have shown significant promise in the field of hydrology
    - They can capture temporal dependencies
    - They have memory cells that can retain information over extended periods

- Chosen LSTM -> 250 hidden size

Input:
Forcing data
Basin attributes

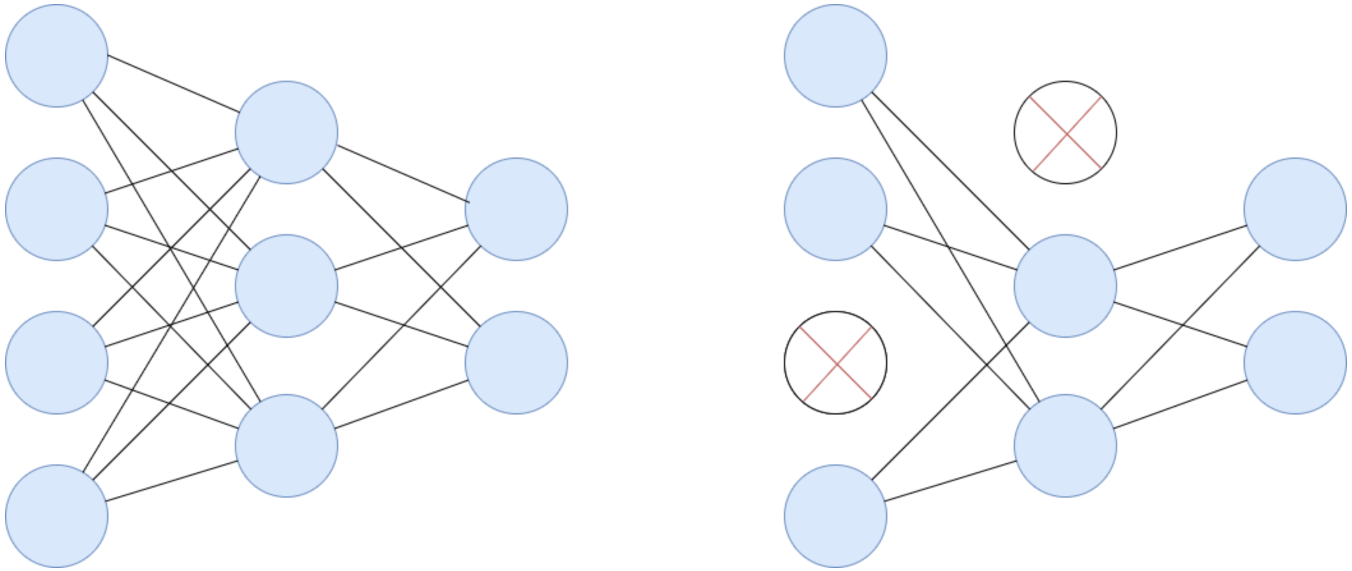



Output:
Discharge prediction

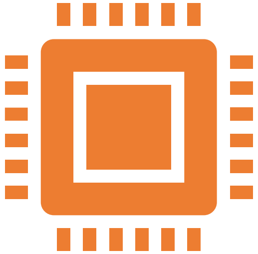
# Monte Carlo Dropout (MCD)

- For chosen LSTM model, MCD was used:
  - Provides uncertainty estimation by taking N samples
  - Regularization technique, preventing overfitting
  - Allows for creating an ensemble

- Number of samples -> 1000
- Dropout rate -> 0.2, 0.3, 0.4, 0.5

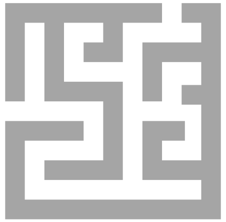


# Evaluation Metrics



## Deterministic:

**NSE**, MSE, RMSE, KGE

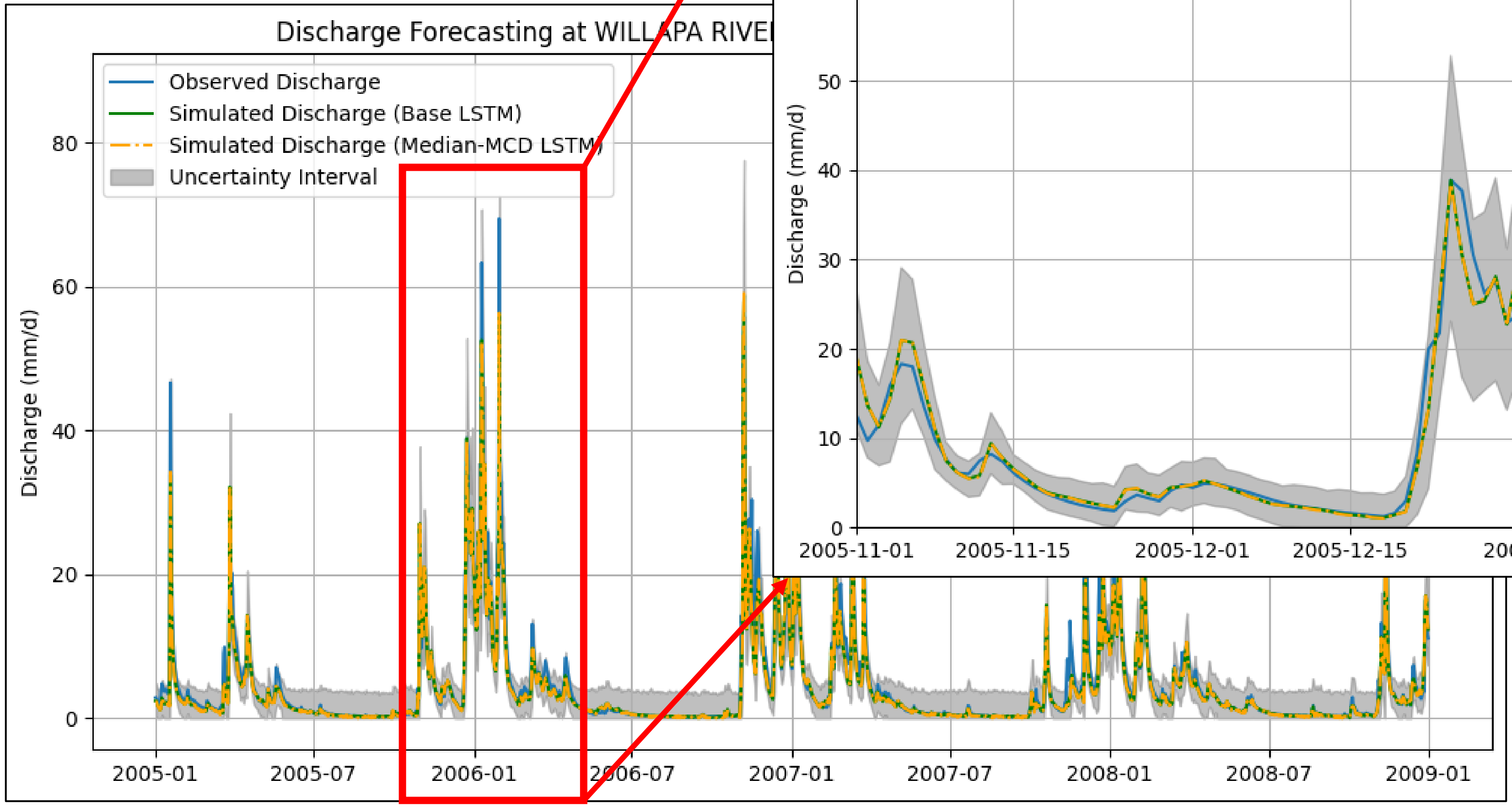


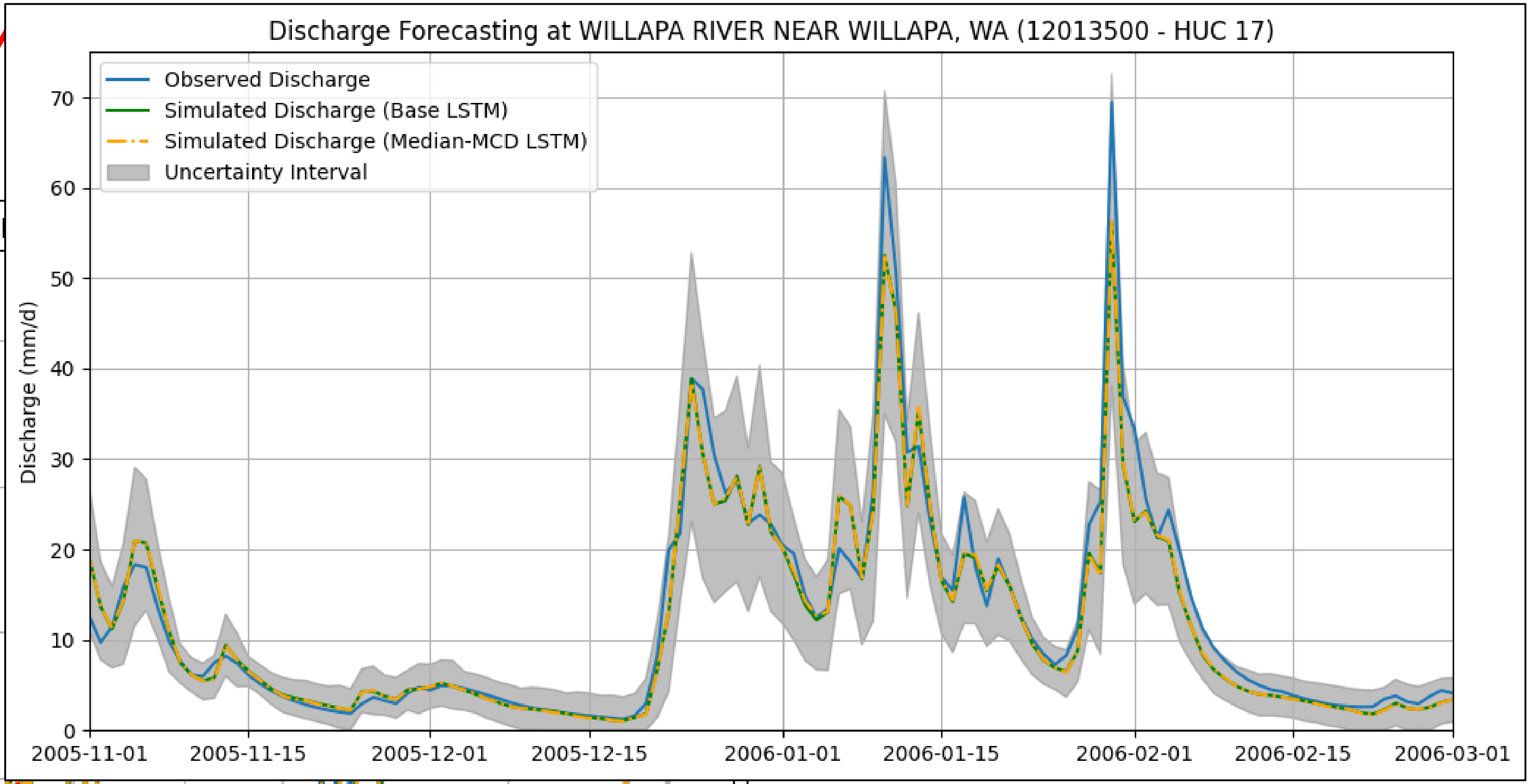
## Probabilistic:

PICP -> Reliability

PINAW -> Informativeness

# Results 1: Discharge Forecasting



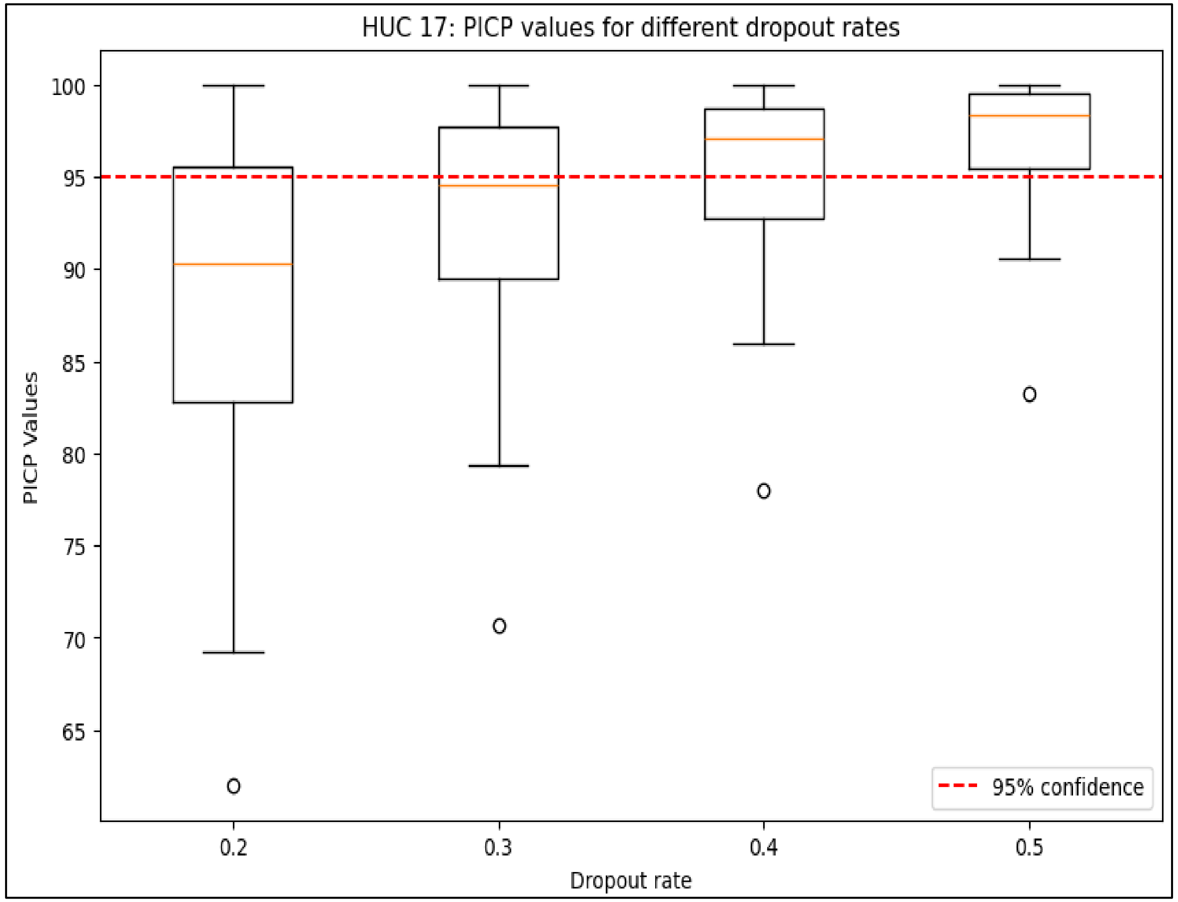




NSE: 0.86
PICP: 95.48
PINAW: 0.75

# Result 2: Uncertainty analysis

- The desired dropout rate was determined
- Based on the 95% confidence interval -> dropout rate 0.4

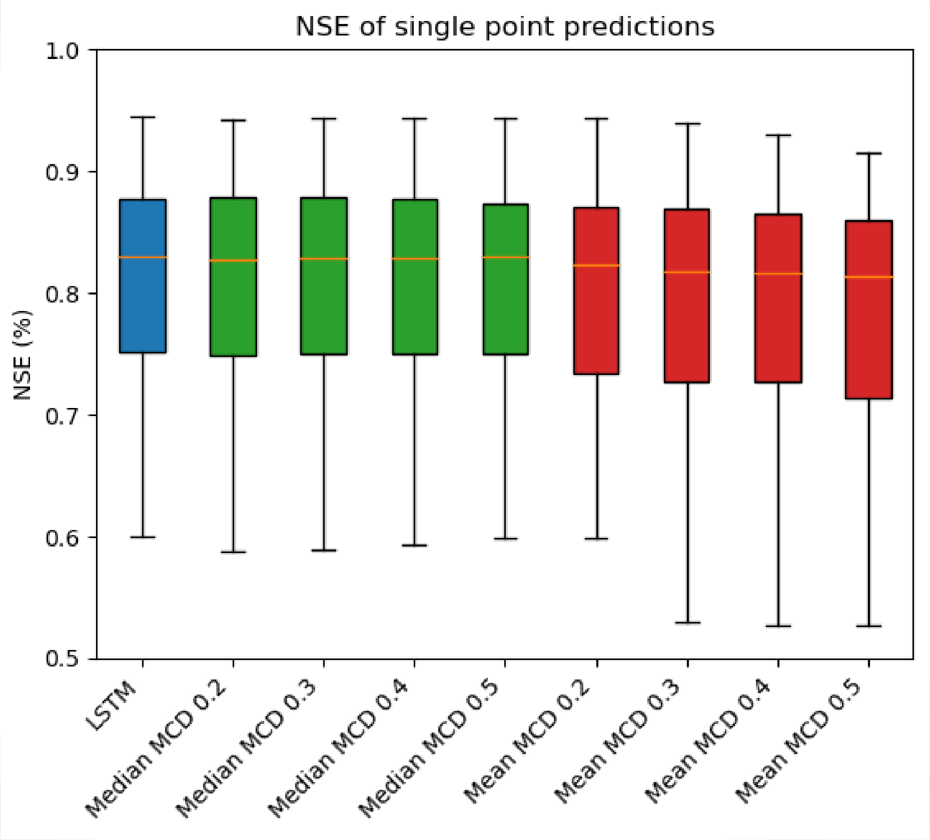
| MC dropout rate | Median PICP | Median PINAW |
|---|---|---|
| 0.2 | 90.28 | 0.7 |
| 0.3 | 94.5 | 0.89 |
| 0.4 | 97 | 1.09 |
| 0.5 | 98.4 | 1.31 |



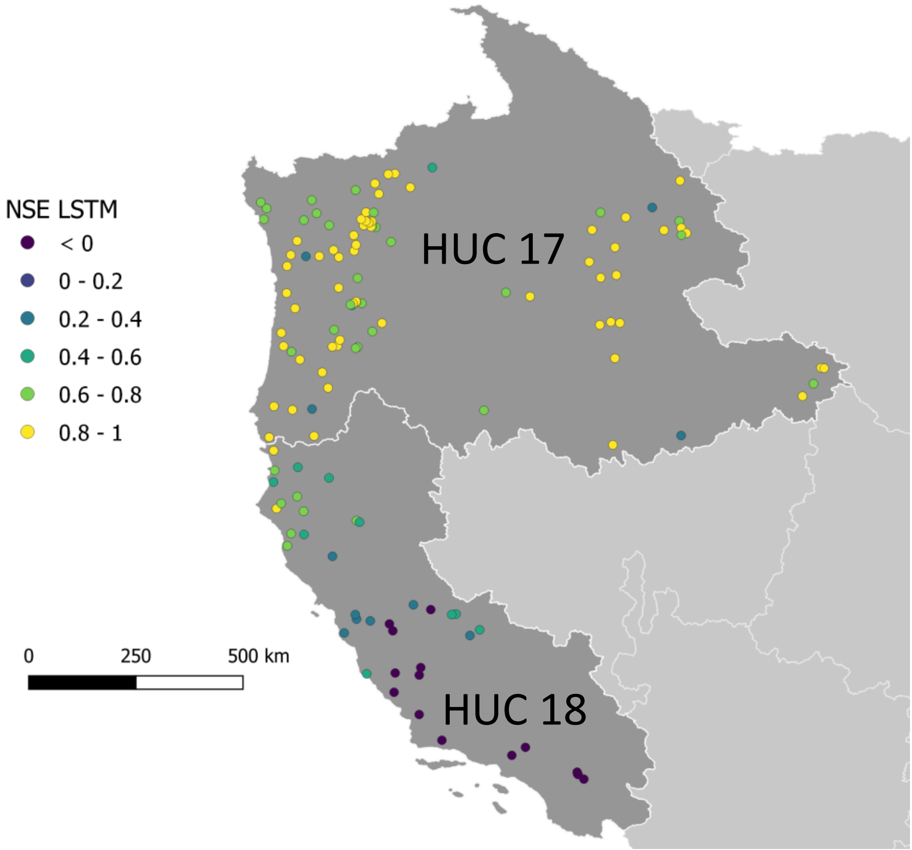
# Result 3: Single point prediction

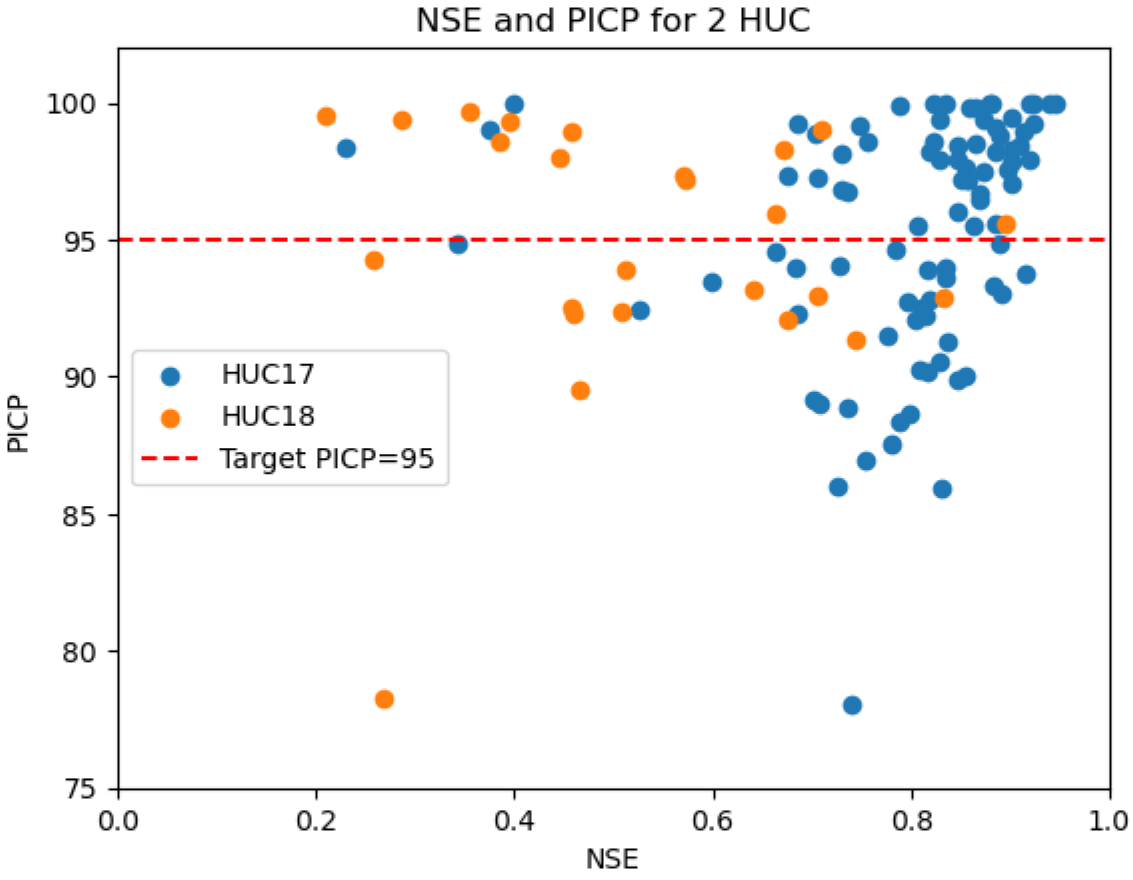
- Median of MCD is equivalent to LSTM prediction
- Mean of MCD performs worse than LSTM predictions

| Correlation | Median MCD | Mean MCD |
| --- | --- | --- |
| Dropout rate = 0.2 | 0.9911 | 0.6315 |
| Dropout rate = 0.3 | 0.9938 | 0.4988 |
| Dropout rate = 0.4 | 0.9951 | 0.4342 |
| Dropout rate = 0.5 | 0.9928 | 0.3978 |

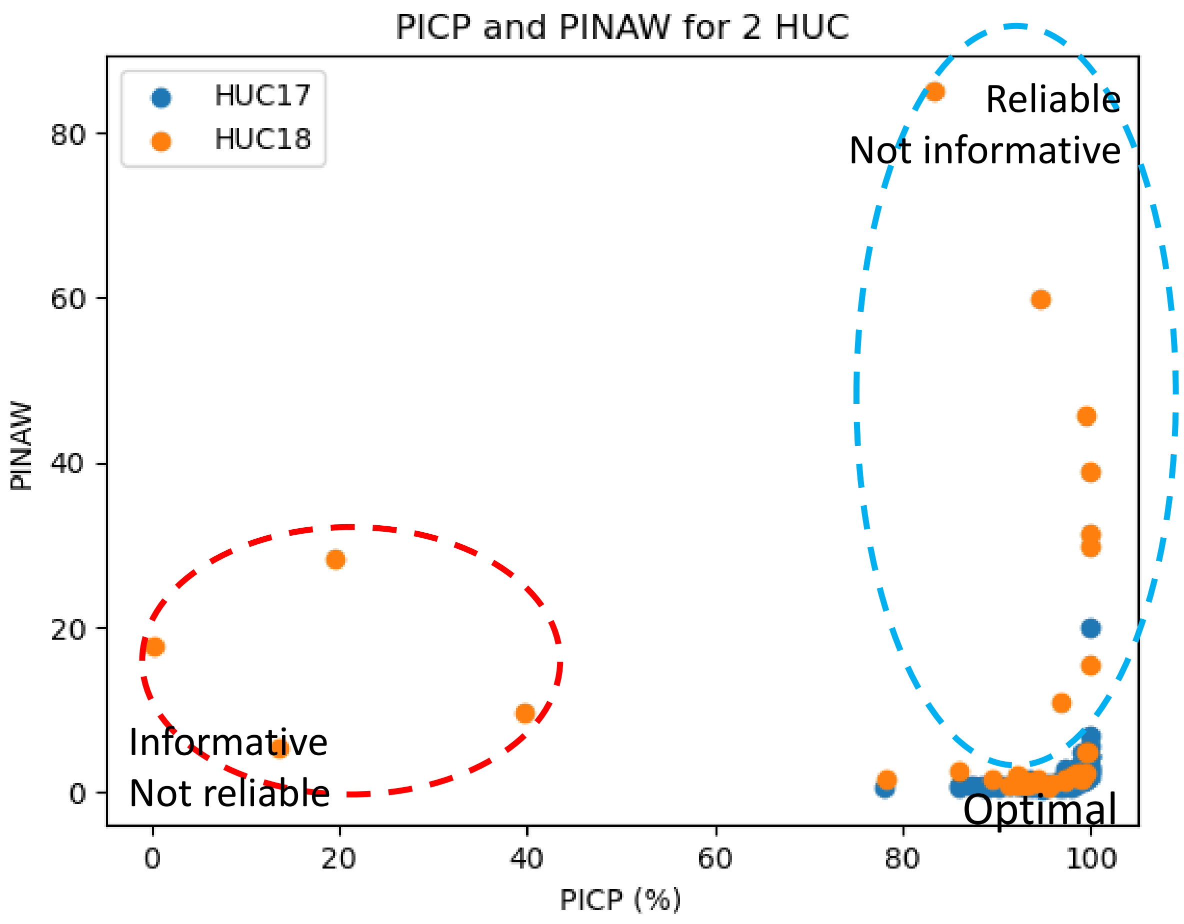


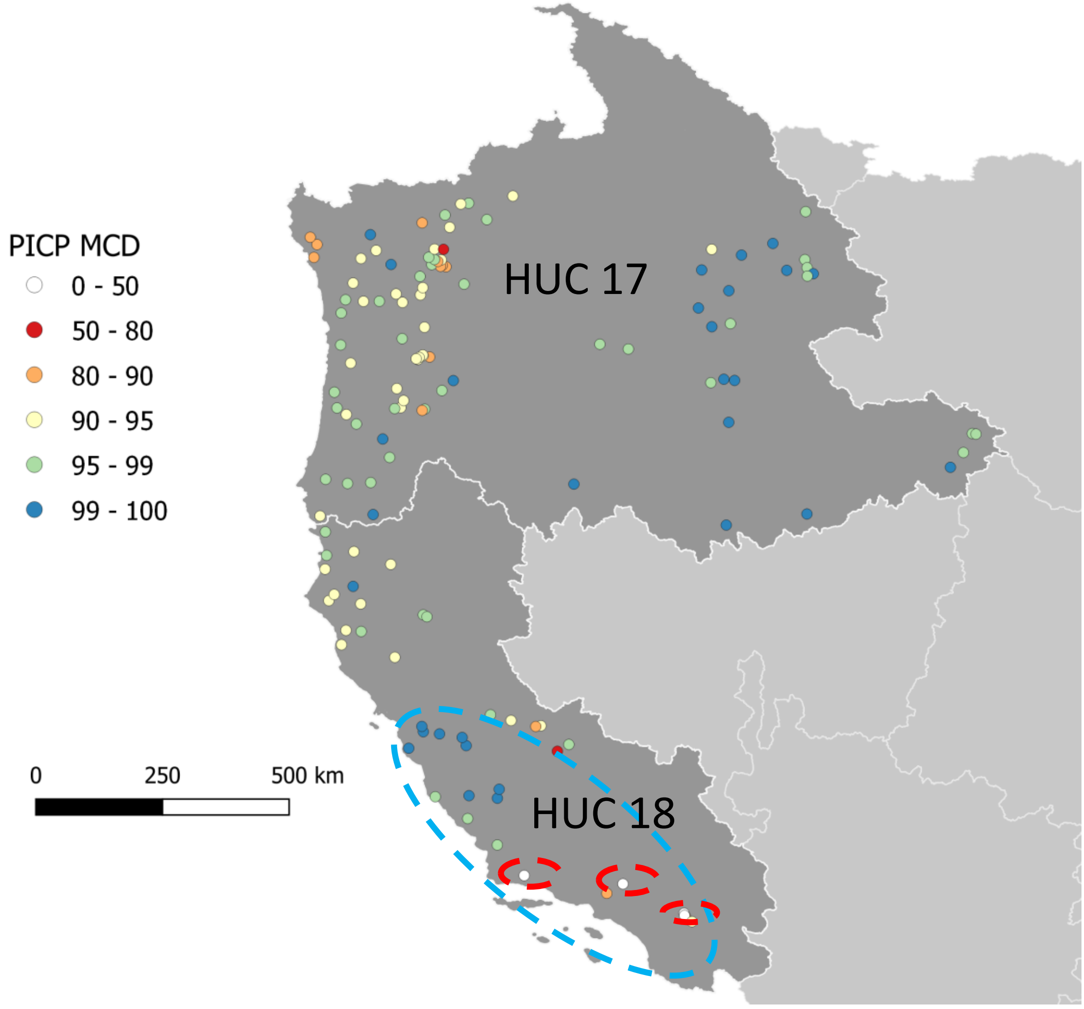
# Result 4: Transferability



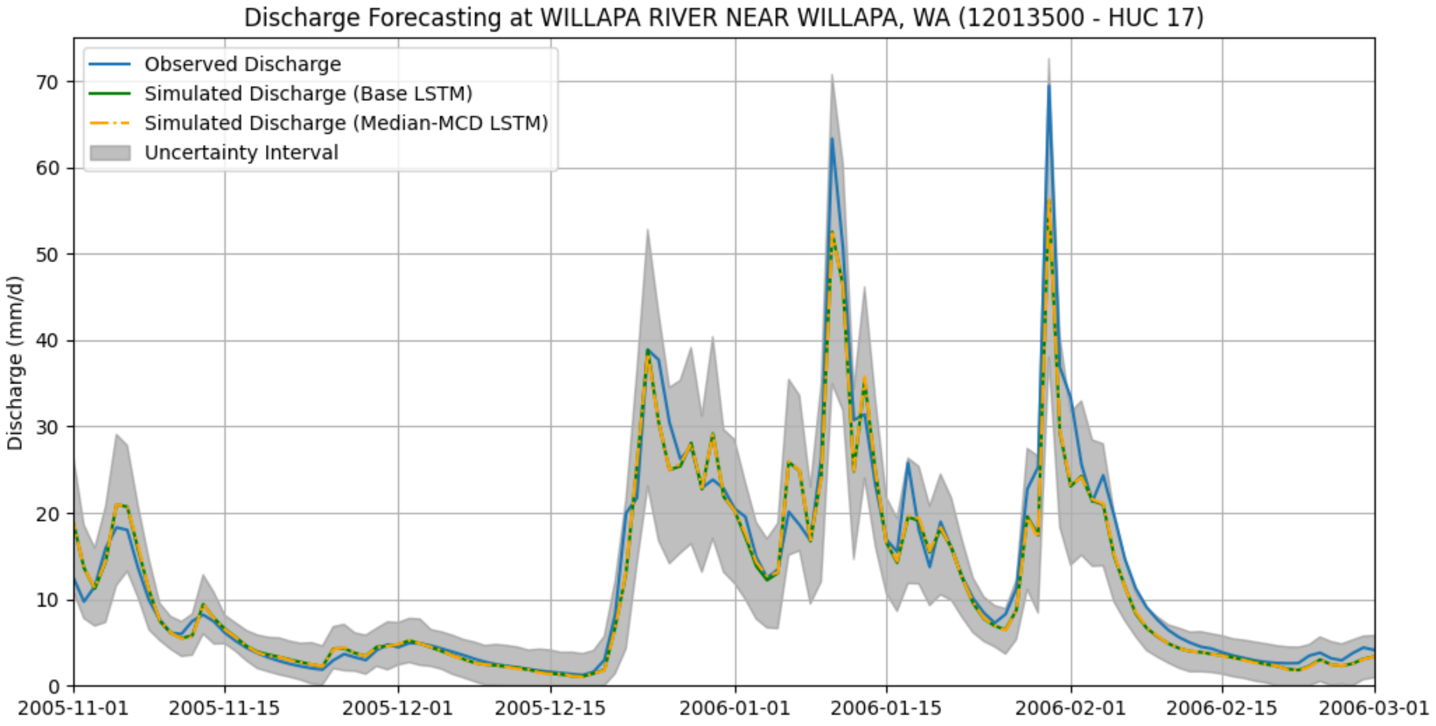
# Result 4: Transferability



# Conclusion

- LSTM hidden size should be large enough to implement MCD
- MCD produces reliable confidence interval when dr > 0.4
- Median MCD prediction is equivalent to LSTM (independent from dr)
- MCD tends to be not informative when applying to another HUC
- It is difficult to evaluate MCD with PICP and PINAW. A unified metric is needed




# Reflection

- Our original plan was to use three forms of Mixture Density Networks as well
- If we have more time, we will probably look into why MCD shows different 'behaviors' when applying HUC 18

# Thank you for your attention

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# Logbook

| Week | Date | Actions | Kind of task | Main Responsible | Comments |
|---|---|---|---|---|---|
| 6 | | | | | |
| | 22-12 | Kick-off meeting | Meeting | All | |
| | | Data Import/Processing | Processing Data | Hang | |
| 7 | | | | | |
| | 08-01 | Meeting Supervisor | Meeting | All | |
| | | Data Labeling | Processing Data | Hang | |
| | | LSTM | Reading Paper and Implementation | Dwiva Thomas | |
| | | Monte Carlo Dropout | Reading papers / workshop / implementation | Thomas | |
| | | Evaluation Metrics | Reading paper | Konstantina | |
| | 12-01 | Preliminary Presentation | Presentation | All | |
| 8 | | | | | |
| | 15-01 | Meeting Supervisor | Meeting | All | Note: we scrapped our previous working, starting anew with neuralhydrology |
| | | Getting to know Neuralhydrology | Reading / coding | All | |
| | | Importing data | Coding | All | |
| | | Training LSTM model | Coding | All | |
| | | MCD | Coding | All | |
| | | Metrics | Reading / coding | Konstantina | |
| | 18-01 | Meeting Supervisor | Meeting | All | |
| 9 | | | | | |
| | 23-01 | **Exam Preparation** | **Exam** | **All** | No work done on project during this time |
| | | MCD | Coding | Dwiva, Hang | |
| | | Metrics | Coding | Konstantina, Hang | |
| | | ReadMe | Writing | Thomas | |
| | | Notebook Layout | Reading / coding | Thomas, Konstantina | |
| | 25-01 | Meeting Supervisor | Meeting | All | |
| | | UMAL/CMAL | Coding | Hang | |
| | | GMM | Coding | Dwiva | |
| 10 | | | | | |
| | 30-01 | Meeting Supervisor | Meeting | All | Focus on MCD |
| | | LSTM hidden layer | Coding | Dwiva Konstantina | |
| | | MCD - dropout | Coding | All | |
| | | MCD - ensembling | Coding | All | |
| | | Notebook Layout | Coding / writing | All | |
| | | Repository | Writing | All | |
| | | Presentation Slides | Designing | All | |
| | 02-02 | **Final Presentation** | **Presentation** | **All** | |
| | | **Final Deadline** | **Deadline** | **All** | |