Tools for Improving Model Predictions

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Waterloo, Ontario

Bryan Tolson

Assistant Professor

Department of Civil & Environmental Engineering

Frank Seglenieks

Angela Maclean

University of Waterloo

My General Contribution to IP3

- Bring analysis tools to IP3 to help modellers build better models
- Focus on the development and application of optimization tools to minimize model prediction error
- When optimization algorithms are applied to model calibration problems, it is usually called Auto- or Automatic-Calibration

Preferred Optimization Algorithm: DDS

- Dynamically Dimensioned Search (DDS) algorithm [Tolson & Shoemaker, 2007]
- A new tool tailored to help environmental modellers more effectively & efficiently calibrate their models
- Simple and fast approximate global optimization algorithm for automatic calibration
- Designed specifically for automatic calibration (modellers)

Key to DDS

- Roughly mimics what a typical modeller would follow when they manually calibrate a model
  - Start at an initial solution & try to improve it
  - Always search around best known solution
  - Early in search, change MANY model parameters simultaneously
  - Later, change FEWER model parameters simultaneously
  - Near end of search, change only 1 parameter at a time
- Why mimic a hydrologic modeller?
  - because manual model calibration has and continues to generate acceptable model results since the very first hydrologic models

Why do we Need to Calibrate Models?

- Not enough resources to sample every parameter across the basin (LAI, saturated hydraulic conductivity etc.)
- Even when sampled, model parameters are typically sampled at a point whereas most of the models we apply require effective HRU/GRU parameter values
- Some parameters are more conceptual and their measurement is difficult or impossible (one example is D_{100} in MESH)
- <u>Calibrating model parameters will improve model prediction accuracy</u>

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Why do we Need Optimization Algorithms for Calibration?

- In some circumstances, we don't!
- Many times we do - too many parameter combinations for modellers to feasibly explore
  - → Auto-calibration of model parameters will improve model prediction accuracy (perhaps insignificantly) over a manual calibration result
- Will save modeller's time!

IP3 Activities to Date

- Make DDS available to IP3 modellers:
  1. specific implementations for a few modellers
  2. general implementation strategy for MESH community model (and other models)
- Application of DDS to a few 1-grid,1 GRU MESH (ver 1.00f) models of various basins
  - initial findings and user guidelines

DDS for MESH Program Design

- Develop framework for researchers using ‘desktop or command line versions’ versions of MESHto calibrate with DDS
- Enable modelers to use DDS to calibrate any set of user selected model parameters:
  - No source code recompilation necessary
  - Keep DDS and MESH model as separate executables which allows for independent development of each program
  - Requires a ‘connector’ executable program for communication that is unique for each model type/version

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Connector Program (Frank)

- Purpose is to transfer DDS generated parameter sets to MESH model input files
- Working towards an exhaustive list of model parameters
  - started with all hydrologic parameters, should include all CLASS parameters
- Connector program is general – e.g. can be used for Monte Carlo simulation purposes

DDS for MESH Program: Ongoing Work

- User documentation close to completion
- From model developers we need some model parameter information:
  - exhaustive list of parameters you would possibly consider changing
  - subset of above parameters you would recommend for calibration
  - initial ranges for each parameter
  - any relationships between parameters that constrain or define their feasible values beyond simple ranges:
    - e.g. Parameter A ≥ Parameter B

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DDS for MESH Program: Ongoing Work

- Initial <u>Guidelines</u> for using DDS with MESH
  - How many parameters should I calibrate with DDS?
    - however many you would have tried changing during manual calibration
    - anywhere from ~10 to around 30 have worked before
  - How many model runs will I need?
    - however many can be completed by the time you want a result (e.g. overnight or over the weekend)
    - probably at least 500-1000 to have some confidence the final result is not a poor solution

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DDS for MESH Program: Ongoing Work

- Initial Guidelines for using DDS with MESH
  - How important are the parameter ranges?
    - can be very important and do impact DDS efficiency
    - they can always be changed (increased) in a second or third DDS optimization run
  - What initial/starting parameter set should be used?
    - two approaches are:
      1. program finds one based on a random sampling experiment
      2. modeller provides one
    - recommend #2: the more modelling knowledge you provide DDS, the better it should do
    - consider some results …

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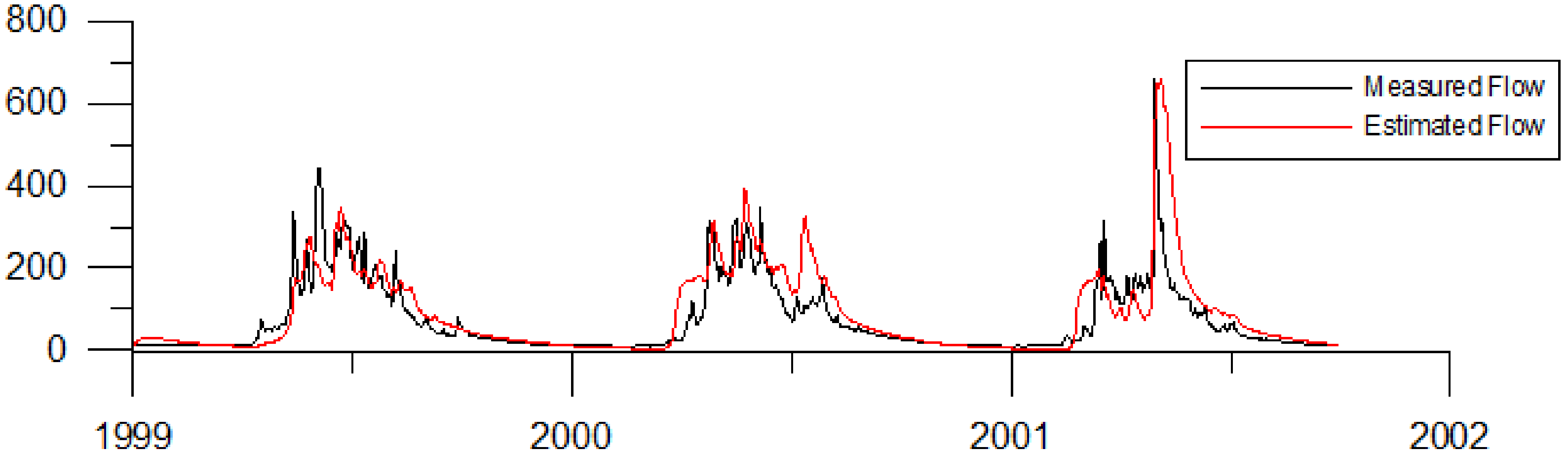
Initial Parameter Set in DDS-MESH Auto-Calibration

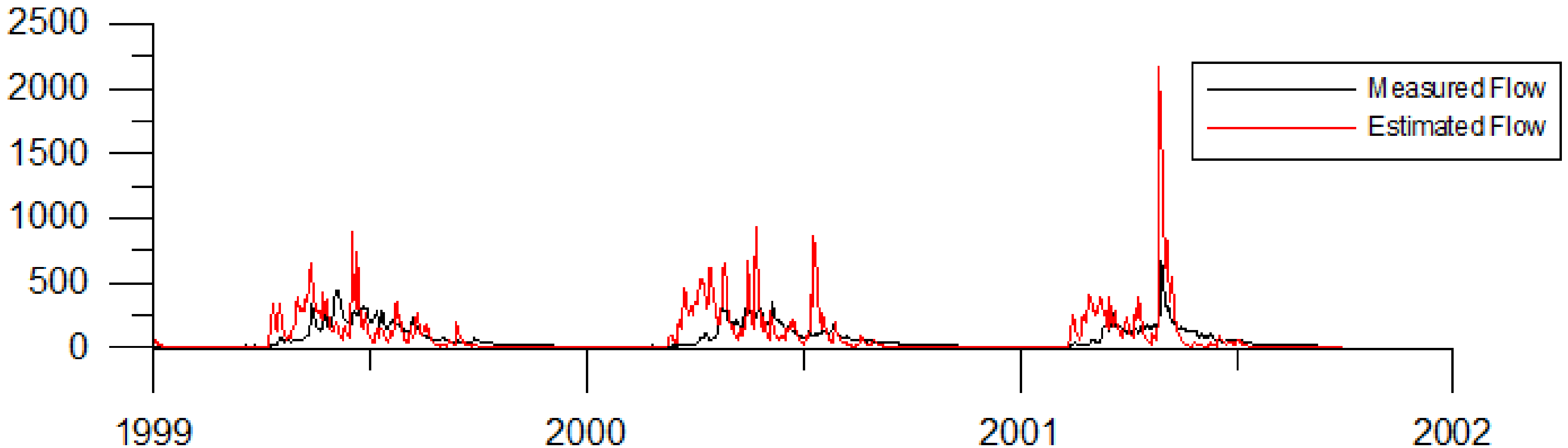
- Before you calibrate it can be very important to have a reasonable starting point (initial parameter set)
- The hydrograph below is the calibrated result for Smokey River watershed, using a good initial starting point



Nash = 0.518

Initial Parameter Set in DDS-MESH Auto-Calibration

- Same model was recalibrated five different times, each time using a new random initial parameter set
- Same computational time as previous result with a good starting set
- Results for each experiment were consistently poor - one of the calibrated hydrograph is presented below.



Nash = - 1.929

How can we Combine Field Sampling and Calibration?

- From a model calibration perspective, we are really interested in two aspects of parameters that are measured in the field
  1. What is the expected or most likely parameter value?
  2. What is the estimated range of the parameter?
- Really would like these numbers at the GRU scale but …

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Future IP3: A Multi-objective Framework for Model Application and Development

- Models must evolve/improve based on all available data
- If a model is developed (i.e. optimized) for streamflow, it is unlikely to predict other state variables of system as well as it could
- Conversely, if a model is developed (i.e. optimized) to predict SWE, it is unlikely to predict streamflow as well as it could

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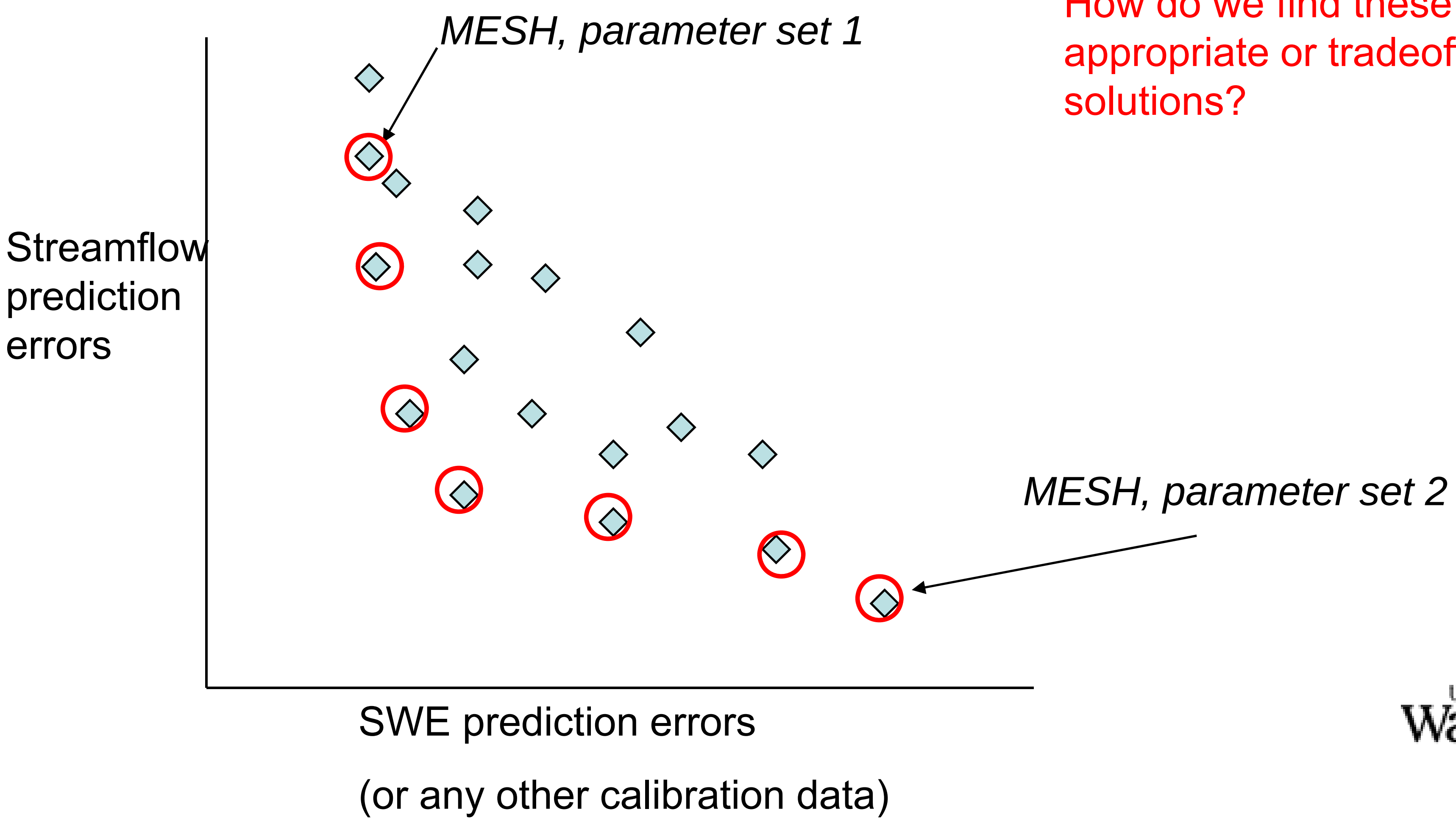
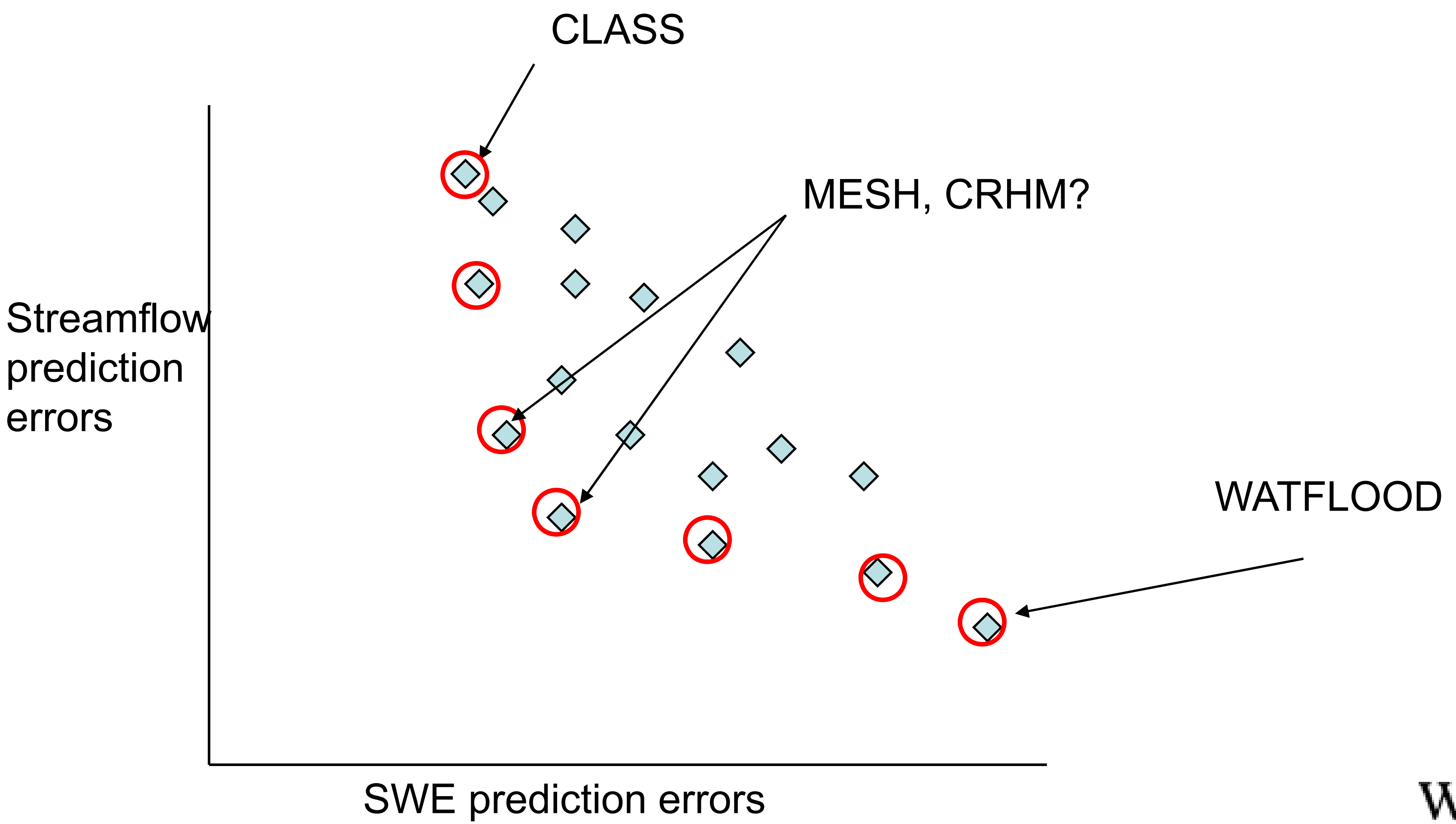
Conceptual example showing spectrum of model prediction quality

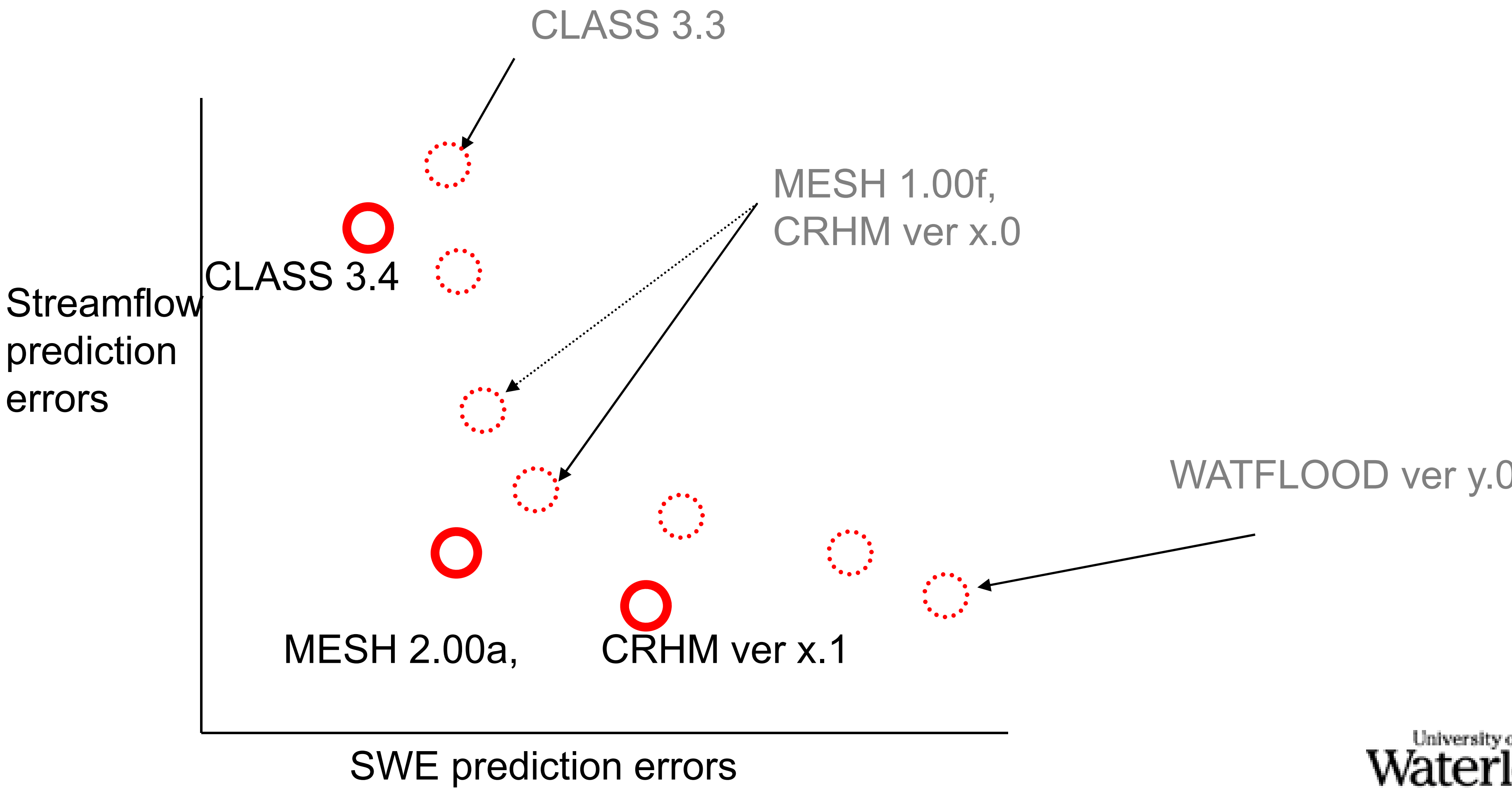
How do we find these appropriate or tradeoff solutions?



Perhaps (?) with our IP3 models we have roughly the following



Ideally, as IP3 Models Improve we would like to see…



Goals for IP3 Work

2. Generate baseline (best or optimized) MESH parameter sets for each IP3 basin
   - note that other modellers may already have identified a very good parameter set
   - started with 1-grid, 1-GRU model of each basin
     - suspect that most basins require more than one GRU to generate reasonable results
   - move to more spatial discretization
   - What level of predictive improvement do we see when we include more grids, more GRUs?

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Goals for IP3 Work

3. Improved Predictions in Ungauged Basins (PUB)
   - Based on all IP3 (and other available basins), generate a default MESH model parameter set that can be recommended for other Cold Region Basins in Canada
   - 7-10 basins with calibration data
   - Find the best "average" parameter set
   - Large scale optimization study
   - Results will also yield multiple parameter sets → can describe prediction uncertainty

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